UNIVERSITY
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RADIO WAVE PROPAGATION IN THE ARCTIC

Interim Scientific Report No. 1
For Period
April 15, 1954 to July 15, 1955

AFCRC-TN-55-579

Air Force Contract No. AF 19(604)-1089

Air Force Cambridge Research Center
Cambridge, Massachusetts

GEOPHYSICAL INSTITUTE

OF THE

UNIVERSITY OF ALASKA

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The object of this project is to conduct studies, directed towards the improvement of communication systems, of tropospheric and ionospheric radio wave propagation in the arctic.

Air Force Research Contract No. AF 19(604)-1089

Report prepared by:

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Report approved by:

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August 15, 1955

The research reported in this document has been sponsored by the Air Force Cambridge Research Center, Air Research and Development Command.

SECTION I

PURPOSES OF CONTRACT

To conduct arctic propagation studies of both tropospheric and ionospheric modes of propagation directed towards the improvement of communication systems. Specific items to be investigated include the following:

1. Study of ionospheric back-scatter at frequencies in the range of 5-25 mc utilizing either the Communication Zone Indicator or a sweep frequency recorder to determine:
   a. The usefulness of ionospheric back-scatter in auroral regions in determining optimum frequencies for HF point-to-point and ground-to-air communications.
   b. The incidence of Sporadic E and auroral curtains.
2. Study direct auroral reflection at 100 mc and higher frequencies depending on availability of equipment.
3. Study the propagation on an existing microwave link.
4. Study the prediction of auroral and ionospheric storms.
5. Study "Whistlers", i.e. very low frequencies in the audio range.

SECTION II

ABSTRACT

The report is divided into six main sections. The first five deal in turn with the five main Tasks specified in the contract; the sixth describes three other phases of work also concerned with radio wave propagation in the Territory. The progress in these various fields is summarised very briefly below.

Task No. 1 Sweep-frequency Ionospheric Back-Scatter

No progress was made on this task, owing to lack of equipment.

Task No. 2 Auroral Radar Echoes

An SCR-270 radar was modified for auroral radar research, and two main investigations were carried out with this equipment. The first one was to determine the mode of propagation of V.H.F. auroral echoes; the results showed conclusively that a strong aspect sensitivity exists, due to the auroral ionization being aligned along the lines of force of the earth's magnetic field. The second investigation was to determine the relationship between the radar echoes and the occurrence of visual aurora; these observations showed that the radar echoes are usually closely associated in range and azimuth with visual aurora, but that the visual brightness of the aurora is not the factor controlling the strengths of the echoes.

No echoes were obtained at frequencies greater than 106 mc, owing to lack of suitable equipment.

Task No. 3 Investigation of Microwave Link

The experimental observations carried out on this link showed the absence of significant tropospheric refraction effects, and the work has now been terminated.

Task No. 4 Prediction of Auroral and Ionospheric Storms

The prediction of aurora and ionospheric storms presumes a thorough understanding of the phenomena. A brief review is given of the source of the disturbances, a stream of ionized particles from the sun, and the several influences which are observed during and subsequent to the bombardment of the atmosphere by these particles. Research in several phases of the problem which are in progress at the Institute are mentioned as well as that which is being done on this contract.

The principle effort during the past year on this contract was development of some techniques for a better understanding of the aurora. These are the all-sky camera which is being used to study the development of an auroral display and the photoelectric photometer which appears to be useful in supplying data for an index of auroral activity. Some preliminary results from both of these equipments are presented.

Task No. 5 Whistlers

Observations have shown the fairly frequent occurrence of whistlers at College during the early part of July 1955. Tape recordings of some of these whistlers are now being analysed to determine their frequency dispersion.

Additional Work

Three main phases of additional work, dealing respectively with the tropospheric propagation of V.H.F. radio waves, the diffraction and scattering of V.H.F. radio waves by mountains, and the absorption of H.F. radio waves of the ionosphere were carried out at the Geophysical Institute. Numbers one and three of these were conducted at the request of the Alaskan Command, U.S. Air Force; the second problem was investigated in view of its possible importance in point-to-point communication in the Territory.

SECTION III

TABLE OF CONTENTS

SECTION IV

EXPERIMENTAL WORK

Task No. 1 To Study Ionospheric Back-Scatter Utilizing a Communication Zone Indicator or a Sweep-Frequency Recorder

No experimental work has been carried out on this task, since suitable equipment has not yet been supplied by the Air Force.

The Geophysical Institute has recommended that the National Bureau of Standards C-4 type of sweep frequency recorder be supplied. This new type of recorder is basically an improved version of the C-3 equipment currently being operated at the Geophysical Institute for vertical incidence ionospheric soundings, under a National Bureau of Standards contract. The advantages of this equipment over the Marconi (Canada) LG-17 ionospheric sounder are several, including its American manufacture, the lower cost, and the fact that the personnel of the Geophysical Institute already have many years of experience with the C-3 type of equipment.

Task No. 2 To Study Auroral Reflections at 100 mc and Higher Frequencies, Depending on Availability of Equipment

A. At 100 mc

1. Equipmental

An existing SCR-270-DA radar was reactivated under this project, and operated jointly under this contract and Signal Corps Contract No. DA-36-039 SC-56739. The equipment had been supplied by the Signal Corps; the cost of operating it was charged to this Air Force Cambridge Research Center contract.

The first step was to carry out some major modifications of the equipment to increase its sensitivity to auroral echoes. The main modifications included the addition of a low noise cascode pre-amplifier, an increase of pulse length with a corresponding reduction of receiver bandwidth, and the reduction of p.r.f. with a resultant increase in maximum range. After modification, the sensitivity of this equipment was such that permanent fixed echoes were obtained from mountains at all azimuths out to about 200 or 250 km. The main operating characteristics are listed in Table 1.

Table 1. 106 mc Operating Parameters at College, Alaska

Transmitting:	
Frequency	106 mc
Pulse Length	100 microseconds
Peak Power	100 kw
Pulse Repetition Frequency	100 per second
Antenna	6 dipoles high, 8 dipoles wide quasi-elliptical, 40 dipoles total
Antenna beamwidth	$\sim 15°$ Azimuth, $\sim 20°$ (free-space) in elevation - Beam elevation 5°
Polarization	Horizontal
Receiving:	
Antenna	Same as above
R.F. Amplifier N.F.	4 absolute
Bandwidth	10 kc
Display	1. A-scope, visual only 2. PPI visual and photographic recording
Maximum range displayed	1250 km
Minimum range free of clutter	About 200 km
Minimum detectable signal strength	Less than 10^{-14} watt

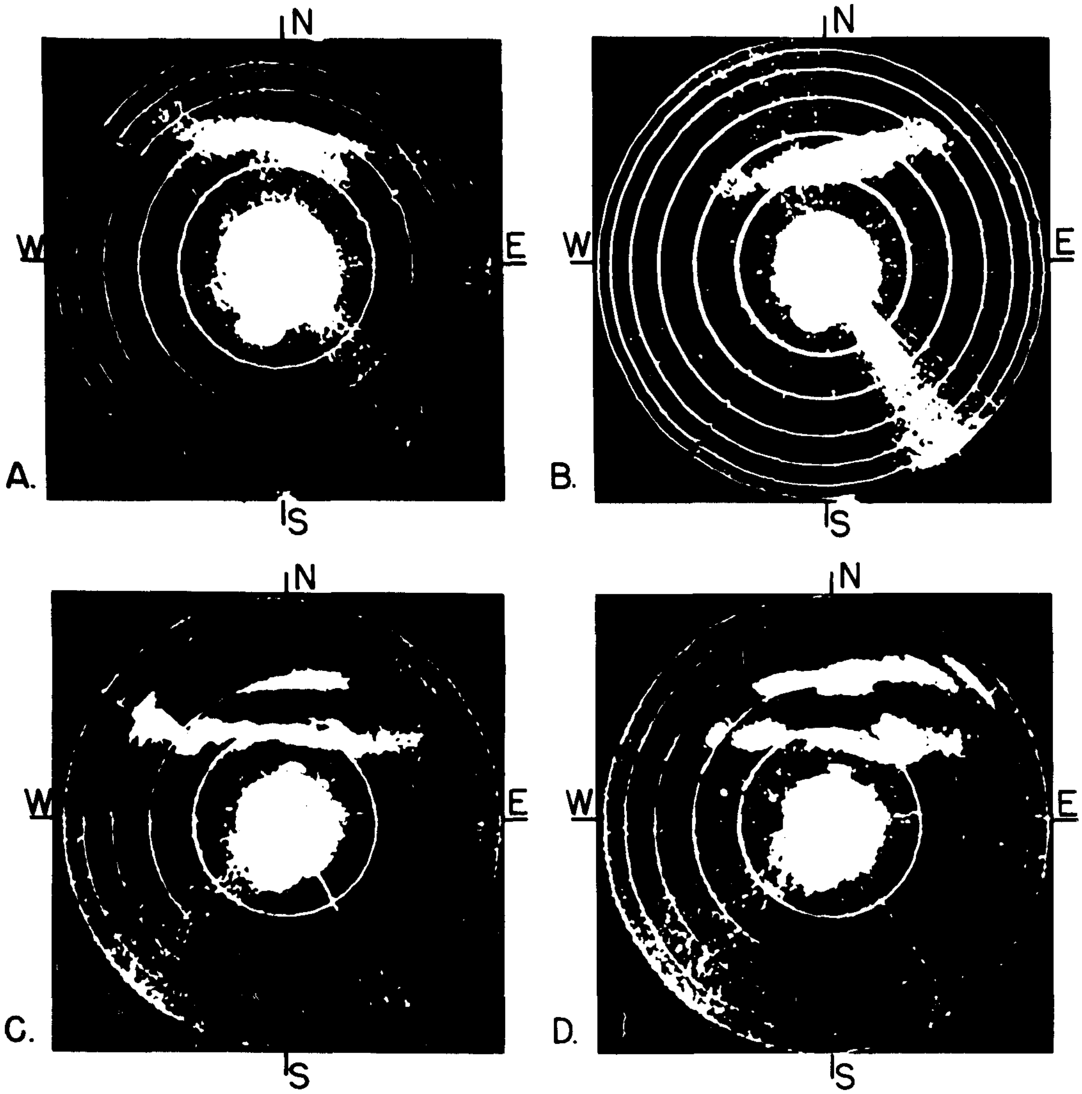
It may be noted that the antenna was tilted backwards slightly. In view of the broad free space radiation pattern of the antenna in the vertical plane, this should have reduced its overall sensitivity for low angles only slightly. One advantage was a probable reduction in depth of any minima of the radiation pattern due to ground reflection effects at low angles. Another advantage was the increased height of the maximum elevation of the first lobe of the antenna.

Operation of the radar with the above characteristics was commenced early in August 1954. At this time aurora could not be seen visually because of the almost continual daylight in Alaska during the summer. Nevertheless returns with all the characteristics of auroral echoes were immediately obtained. Several patterns of behavior became evident even before visual observations were possible.

The radar was operated on several nights during August. Published estimates of magnetic activity and ionospheric storminess for most of these nights indicated normal or quiet conditions. Auroral radar echoes were seen on all of the nights attempted. The echoes were, however, stronger and more persistent on nights of increased magnetic activity.

The strongest echoes obtained corresponded with received powers of about 10^{-9} watt, though the greatest number of echoes were weaker than about 10^{-11} watt. The effective reflection coefficient of the aurora, when averaged over the polar diagram, reached a maximum value of about 3×10^{-4}; the minimum effective reflection coefficient required to give a perceptible echo for this equipment is about 3×10^{-9}. These values correspond to equivalent target areas of about 5×10^{5} square metres and 5 square metres respectively.

Figure 1 illustrates one type of echo pattern which resulted from the narrow beam antenna and high sensitivity of equipment. The similarity of these patterns to the type obtained by Bullough and Kaiser is striking[1], and suggests that V.H.F. radar may be a useful tool in estimating the orientations of auroral arcs. The orientation of Figure 1a shows a slight rotation clockwise with respect to geomagnetic East-West. Such rotation was a consistent feature during the period some six hours before local midnight. The slight rotation in the reverse direction, as illustrated in Figure 1b, was characteristic of the period some six hours after local midnight. No orderly behavior was noticed near midnight, as suggested in Figure 1c and Figure 1d. The time dependence of the orientation thus outlined was similar to published measurements of the orientations of auroral arcs obtained visually (see for example reference (2)).



EXAMPLES OF RADAR ECHOES FROM AURORA
COLLEGE, ALASKA AUG-SEPT, 1954
RANGE MARKERS AT 200 KM INTERVALS

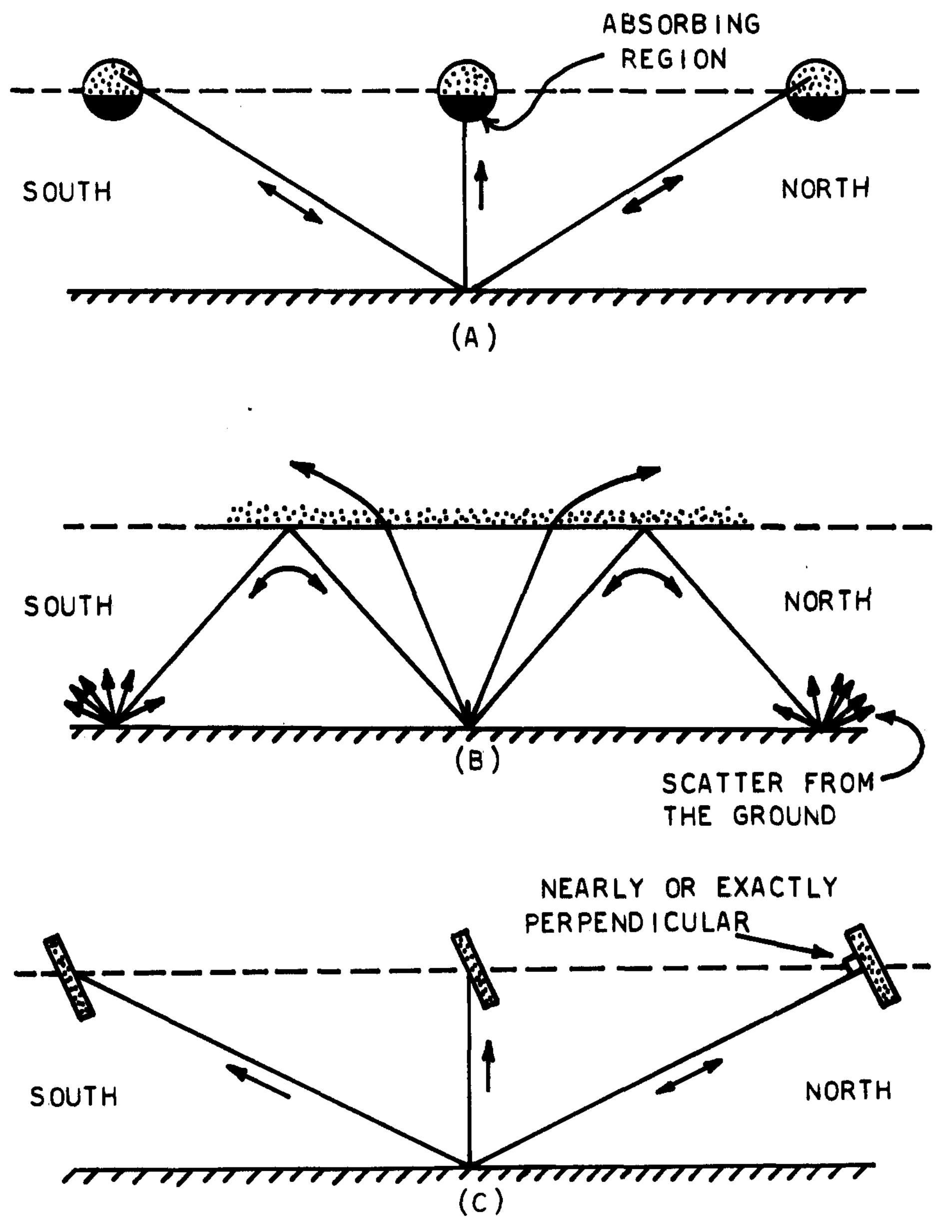
Figure 1

2. Aspect sensitivity of V.H.F. auroral radar echoes

The high sensitivity and good angular resolution of this 106 mc radar was utilized in an investigation of the mode of propagation of V.H.F. auroral radar echoes. Observations of 50 mc auroral echoes made at College during the summer of 1953 by R.B. Dyce[3] showed a marked aspect sensitivity of the aurora, in that echoes were only obtained at low elevations, even when visual forms were seen in the zenith. Similar observations have been reported by the Canadian[4] and Norwegian[5] workers. In order to explain this lack of overhead echoes, three different modes of propagation for auroral echoes have been put forward by the Canadian, Norwegian and United States groups respectively. These are illustrated diagramatically in Figure 2.

The first model, suggested by the Canadians[4], makes use of the fact that "polar blackouts" have been reported during high latitude aurora.[6] These "blackouts", or complete fade-outs of all ionospherically propagated H.F. signals, are due to exceptionally strong absorption of H.F. radio waves in an absorbing layer below the reflecting layers. The Canadian workers suggested that such an absorbing layer occurs immediately below the aurora, thereby preventing the detection of aurora from below, but not affecting radio waves incident upon the aurora from other angles.

The second model, due to Harang and Landmark[5], postulates the presence of horizontally stratified ionized clouds associated with aurora. These clouds are assumed to be capable of reflecting radio waves incident upon them, (at approximately glancing angles) forward towards the ground, where some of the radio waves will be scattered



ILLUSTRATING THREE THEORIES OF AURORAL IONIZATION ASPECT SENSITIVITY

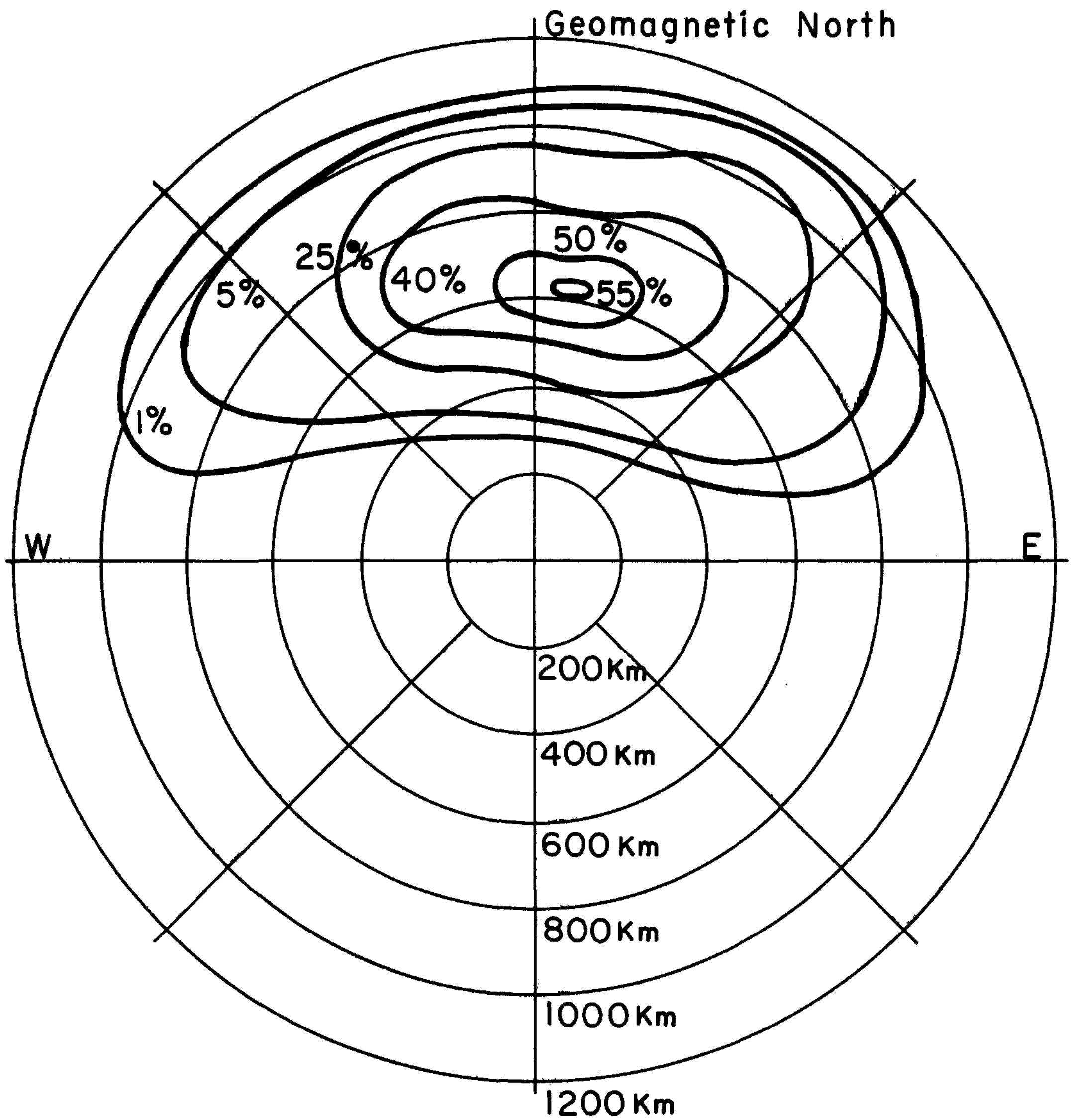
Figure 2

back to the receiver over the same path. V.H.F. radio waves incident approximately normally upon these clouds will be able to penetrate them, owing to insufficient electron density; for this reason echoes will not be obtained from overhead aurora.

The third model suggested by Moore[7] and extended by Booker, Gartlein and Nichols[8] and by Chapman[9], makes use of the fact that the (visual) auroral rays are aligned along the lines of magnetic force. It is postulated that the ionization giving rise to auroral echoes is also aligned along the magnetic lines of force; in this case the strongest echoes will be obtained when the radio waves are incident at right angles to the auroral rays, i.e. when the radio path is approximately perpendicular to the magnetic lines of force. Since these lines of force are (very approximately) vertical at high latitudes, radio echoes would not be expected from overhead aurora.

As illustrated in Figure 2, these theories all explain the absence of echoes from overhead aurora, but they differ in regard to sensitivity to aurora south of the transmitter. The absorption and ground scatter theories predict no azimuthal variation in sensitivity (assuming uniform distribution of aurora across the sky), whereas the theory due to Moore predicts that aurora will most frequently be detected to the magnetic north, and will not be observed to the south of the transmitter.

In order to investigate this aspect sensitivity of V.H.F. auroral radar echoes, a large number of P.P.I. photographs of auroral echoes was amassed over a period of several months. Figure 3 contains the range and azimuth information available from 311 such pictures, all



Contours show expected probability of obtaining auroral echoes, during periods when auroral echoes are seen somewhere on the PPI 'scope

106 Mc/sec

College, Alaska

August – October, 1954

311 samples

Figure 3

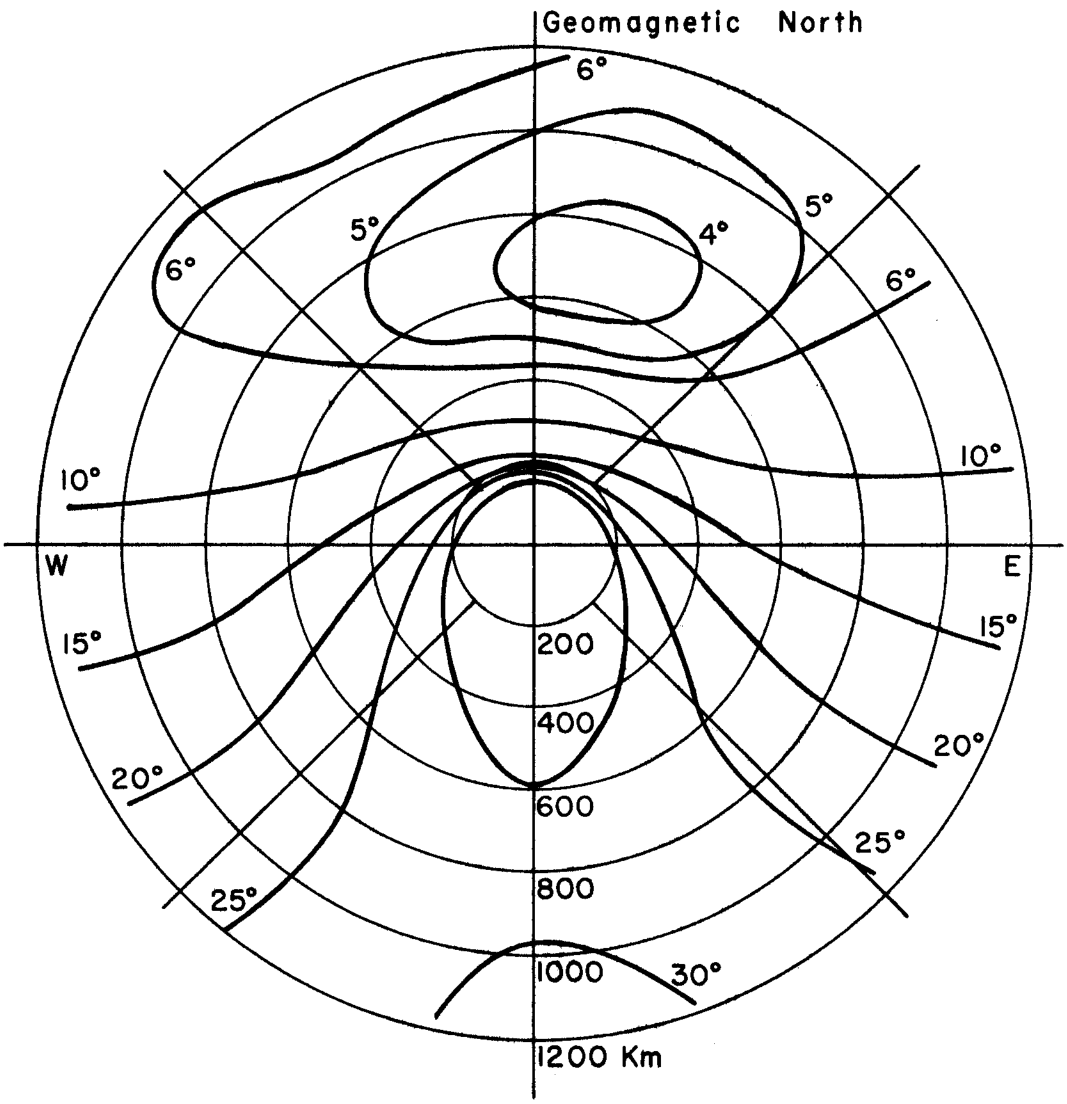
of which included the information for the full 360 degrees of azimuth. The photographs were divided into 100 km range intervals and 15 degree azimuth intervals. The number of occurrences of echoes within each box thus formed were tabulated without regard to signal strength. The quantity of samples made it possible to see a regular behavior rather than a mere scatter plot, and the positions of the several contours shown were easily determined.

It may be noted that the area of each of the boxes mentioned above is approximately proportional to the range. Assuming a uniform average distribution of aurora in a thin layer over the area surveyed, the probability of observing aurora within each box should also be proportional to the range. However the field strength of the echo signal should be inversely proportional to the square of the range for a given scattering coefficient. The overall effect should be to make the probability of receiving an echo (within a given box) depend on a factor inversely proportional to its range.

If columns of ionization such as those postulated by Booker, Gartlein and Nichols[8] are the scattering centers, then the scattering coefficient of each column may be assumed to depend on its aspect, the maximum coefficient occurring when the column lies normal to the path of the radio wave. For columns inclined to this perpendicularity condition by an angle α the echo strength decrease α increases. Echoes weaker than the threshold will of course not be observed, hence the shape of the experimental probability contours should resemble the shape of contours showing constant α .

Careful computations were made to determine the value of α as a function of slant range and azimuth, utilizing the actual value of both inclination and declination as obtained from the D.T.M. charts, after computing great-circle range and azimuth overlays. Such precision was used rather than the simple dipole field of the earth, since it was considered desirable to try and interpret some of the asymmetries of the experimental results. This attention to detail has been criticized on the grounds that the true orientation of the magnetic field 100 km above the surface of the earth is somewhere between the two descriptions, but, on examination of the experimental results, it appears to be well justified.

The computed contours are shown in Figure 4. It will be seen that these agree extremely well with the experimental results of Figure 3, especially when the experimental limitations are remembered. Thus the experimental curves should be displaced slightly toward the radar station compared with the ones showing constant α , owing to the inverse distance effect mentioned above. Also, at very low angles of radiation, the reduced sensitivity of the antenna is probably the dominating factor. This is almost certainly part of the reason for the discrepancy between the experimentally determined probability contours and the α contours at ranges greater than 1000 km. When these two factors are allowed for, the agreement between theory and experiment is remarkable, and must be regarded as a striking confirmation of the near-perpendicularity theory. It should be noted that this model does not deny the possibility of echoes being observed to the south; the experimental observations



Contours of equal angle between a radio ray and the plane perpendicular to a line of the earth's magnetic field, for a height of 100 kilometers, as a function of slant range and bearing from College, Alaska. D.T.M. magnetic field 1945.0 was used.

Figure 4

however show that less than 1% of the 106 mc echoes came from that direction. It should also be noted that the maximum of Figure 4 does not coincide with the auroral zone, as defined by Vestine[10], but in a region about 300 kms north of the zone. This also may be, in part, the reason why the peak probability occurs somewhat nearer than the position corresponding to minimum α .

Conclusion

The excellent agreement between the contours of equal probability of observing auroral echoes and those for equal values of the angle α must be regarded as strong evidence in favor of the "near-perpendicularity" theory.

These measurements therefore suggest that the ionization which causes V.H.F. auroral echoes occurs in surfaces which are parallel to the lines of the earth's magnetic field. The scatter diagram is considerably broader in azimuth than in elevation (the 5 per cent probability contours of Figure 8 cover an angle of about 135 degrees in azimuth and about 15 degrees in elevation). This implies that the reflecting surface is not smooth, but consists of irregularities which are several wavelengths in length (perhaps about 50 meters) and considerably smaller in width (say 10 meters). These elongated scatterers are aligned along the lines of magnetic force.

Further evidence in favor of this interpretation of auroral radar echoes is contained in the Final Report on Task E of Signal Corps Contract No. DA-36-039 SC-56739, submitted by the Geophysical Institute to the Laboratory Procurement Office, Signal Corps Supply Agency, Fort Monmouth, New Jersey, in July 1955.

3. The relation between visual and radar observations of aurora

Most of the experimenters in the field of radar observation of aurora have at one time or another tried to correlate their radio echoes with particular forms in the visible aurora. Some, notably Forsyth and his co-workers at Saskatoon[4,11,12,13] take the position that the echoes do originate within or directly below the region wherein the light of certain types of auroral forms is emitted. However their published results fail to convince certain others, notably Harang and Landmark[5], who argue that, at best, the echoes bear only an indirect relation to the visible aurora. In order to check on this point, a careful investigation was made by taking a large number of simultaneous photographs of the 106 mc PPI display and of the visual forms.

To enable the visual observations to be carried out unobscured by trees, it was necessary to erect an observing tower at the radar site. This consisted of a heated room (8 ft. x 8 ft.), with glass windows on all four sides, supported at a height of approximately forty feet on four telephone poles. An extension PPI display was installed in the room to enable the operator to carry out simultaneous visual and radar observations of the aurora. Permanent records for more detailed examination were obtained by photographing the PPI display and the visual forms simultaneously. Some of these photographs are reproduced in Figures 5 to 9.

A brief description of the method of presentation will aid the reader in understanding the illustration. The photographs of the visible aurora are calibrated in geomagnetic azimuth and in calculated

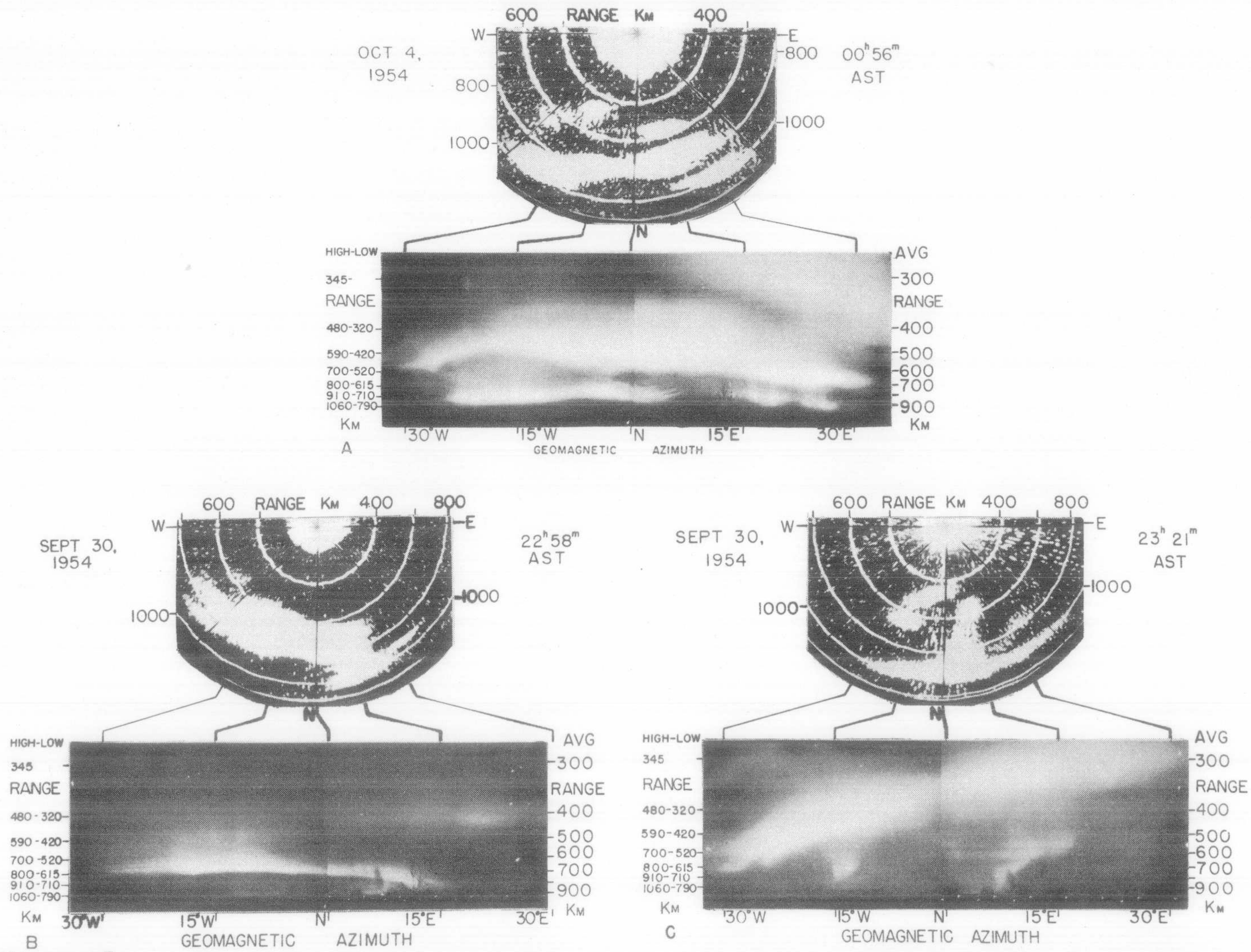


Figure 5

Photographs of Visible Aurora Compared with P.P.I. Presentations of Radar Echoes Taken Simultaneously at College, Alaska — 106 Mc/sec

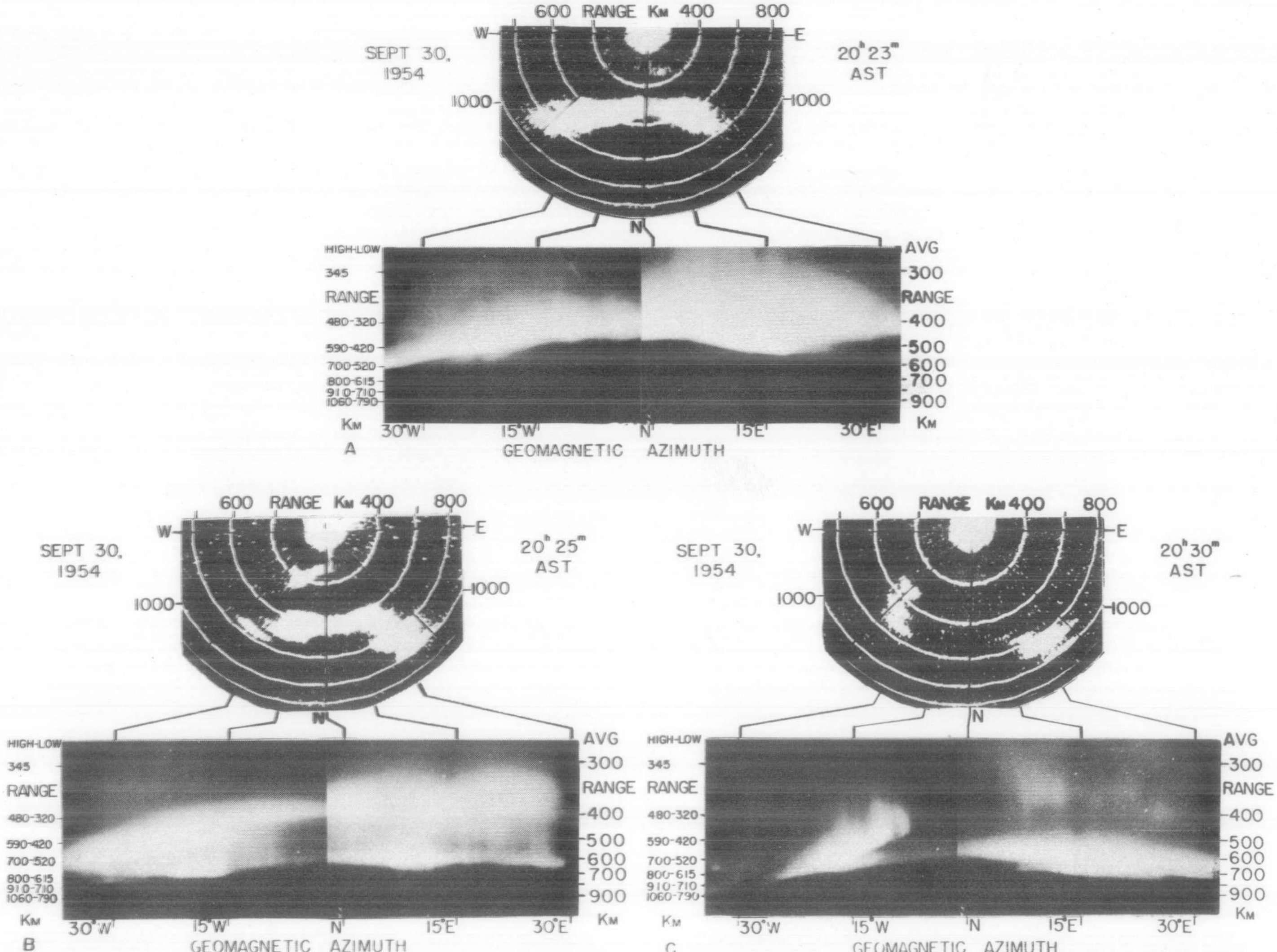


Figure 6

Photographs of Visible Aurora Compared with P.P.I. Presentations of Radar Echoes Taken Simultaneously at College, Alaska -- 106 Mc/sec

slant range of the individual forms, the latter calculations being based upon the assumption that the lower borders of the displays have an average elevation above the earth's surface of 100 km. Although 100 km is the level most commonly seen, elevations as low as 80 km and as high as 120 km are frequently noted[14]. Elevations outside these limits are less common. Calculations of range based on high and low elevations of 120 km and 80 km are also presented on the photographs. The unorthodox presentation of the PPI pictures has been adopted to facilitate comparison with the visible aurora pictures. Thus features on the one which appear relatively high also appear relatively high in the other, etc. Slanted lines connect identical azimuths at the borders of the two types of photograph. Since the exposure time employed in making each type of photograph was about one minute, certain features of rapidly moving auroral forms, particularly rays, appear smeared on the photographs. It should be noted that intense echoes produced somewhat broader traces on the PPI 'scope than did weak ones. The comparison with the visual features can therefore only be approximate.

The correlation of the PPI patterns with expected patterns for the visible aurora is often extremely good. This is illustrated in Figures 5 and 9. Sometimes the correlation is enhanced by an obvious variation with time, as in a and b of the sequence in Figure 6. However, part c of Figure 6 demonstrates that aurora may often be present without the presence of any radar echo. This point if further illustrated in the examples of Figure 7, all of which show more aurora than are indicated by the radio returns. Occasionally radar echoes are observed when no

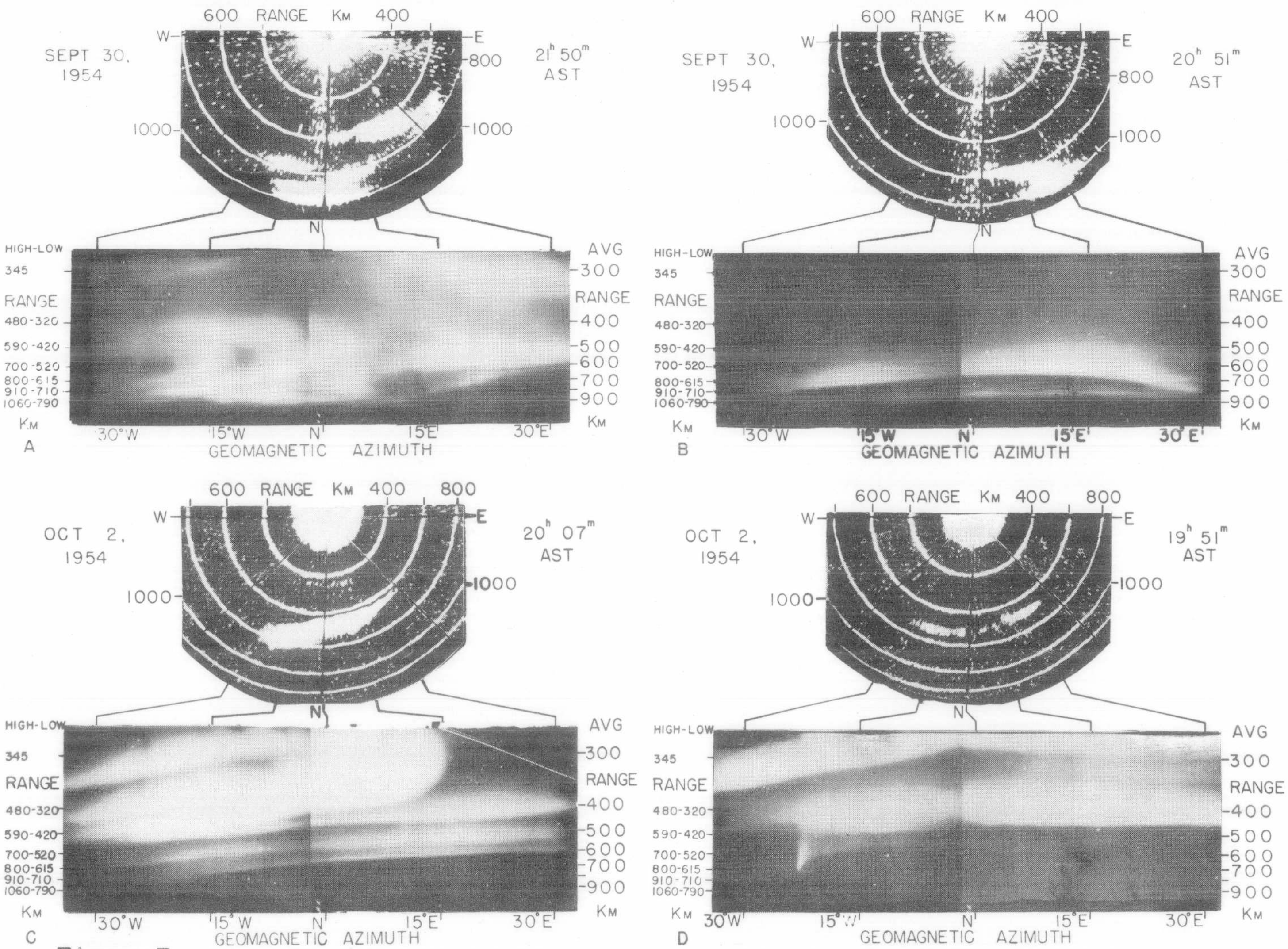


Figure 7

Photographs of Visible Aurora Compared with P.P.I. Presentations of Radar Echoes Taken Simultaneously at College, Alaska –– 106 Mc/sec

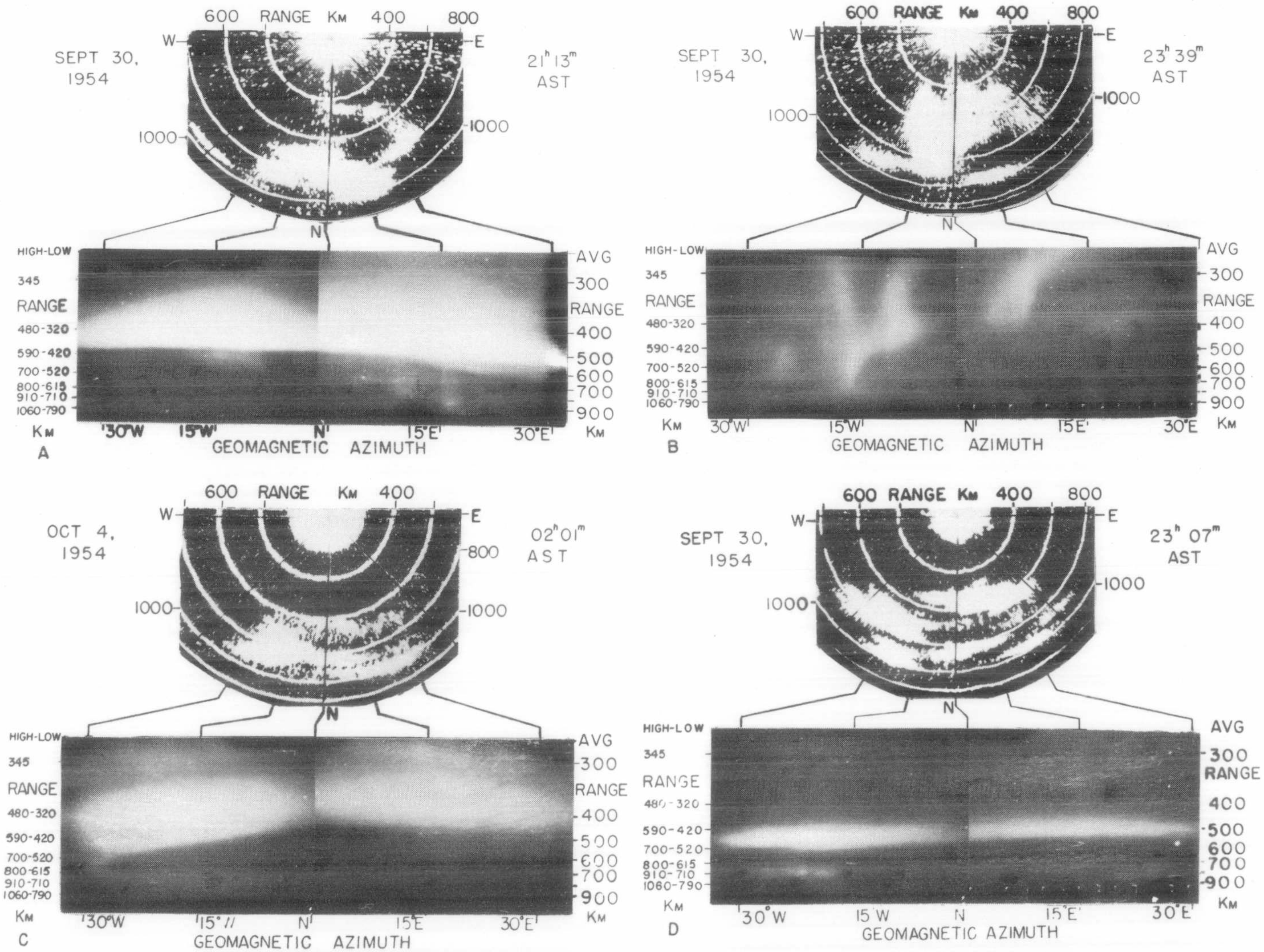
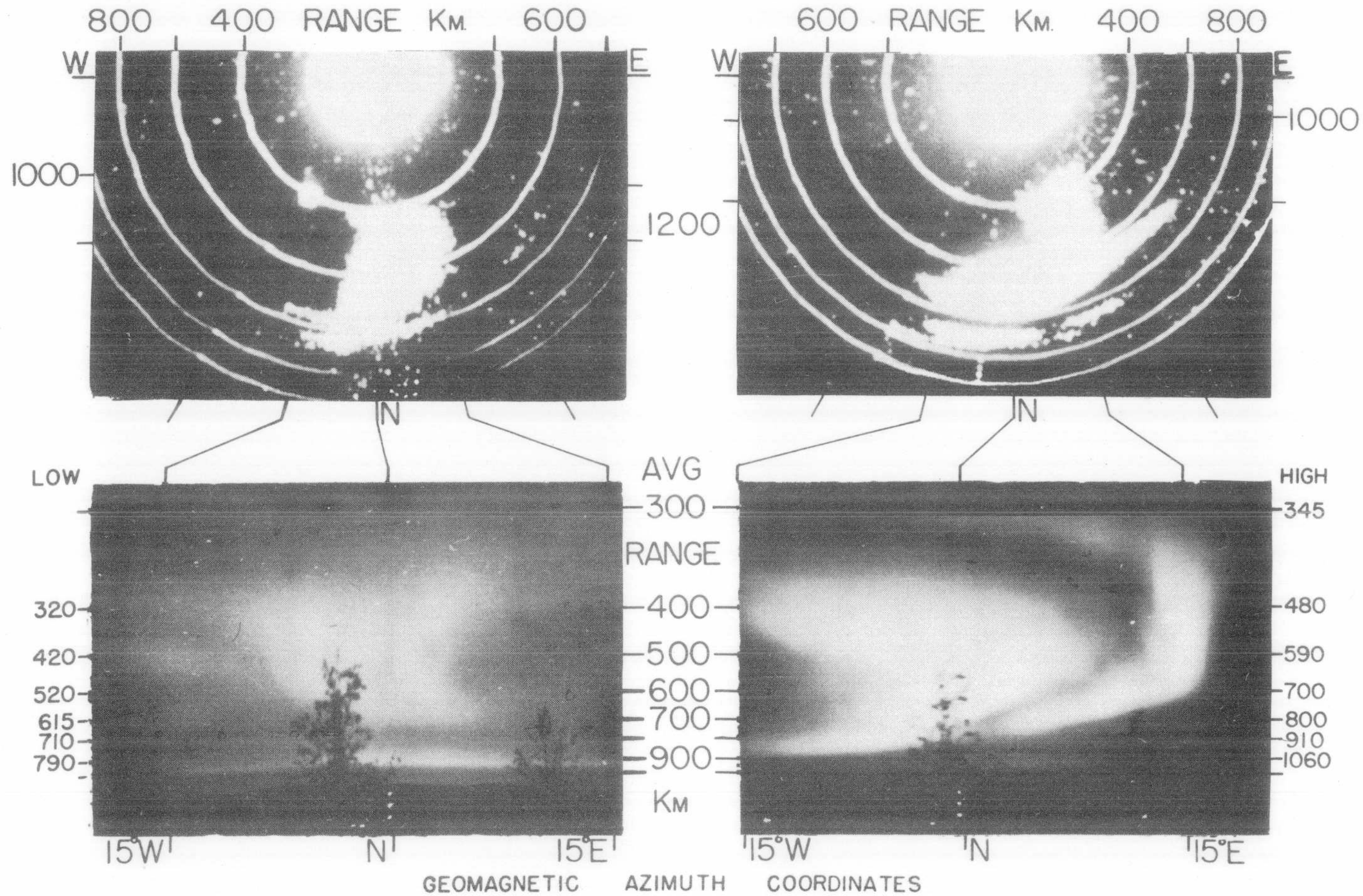


Figure 8

Photographs of Visible Aurora Compared with P.P.I. Presentations of Radar Echoes Taken Simultaneously at College, Alaska -- 106 Mc/sec



SIMULTANEOUS PHOTOGRAPHS OF VISIBLE AURORA AND RADAR 'SCOPE

COLLEGE, ALASKA 106 Mc./sec

Figure 9

Photographs of Visible Aurora Compared with P.P.I. Presentations of Radar Echoes Taken Simultaneously at College, Alaska -- 106 Mc/sec

apparent correlation may be made with visible forms within the elevation limits 80 km to 120 km. Four such cases are shown in Figure 8. However, there remain several possibilities for explaining the apparent lack of correlation. Most obvious is the possibility that echoes may originate occasionally from auroral forms higher than 120 km. From inspection of Figure 8 this may be regarded as only a partial explanation of the difficulty. A more likely explanation is obtained from closer evaluation of the available information.

Inspection of Figures 5 - 9 reveals little correlation between the strength of the radar echoes and the luminosity of the visible forms. Variations in density of a thin cloud cover can account for only a small part of this discrepancy as evidenced by the fairly constant brightness of stars in the many pictures. At times when no aurora is present, the horizon is not discernible on negatives of the exposure normally used; the original negatives of Figure 8 show the horizon quite clearly, indicating the presence of weak, diffuse auroral activity. This diffuse luminosity is always present when radio echoes are observed without direct correlation with brighter forms.

Such occasions are most likely to occur after the critical peak phase of a display when the homogeneous arcs "break up" or give way to a complex of forms including rays. Visual observations of similar events in the sky, when they occur overhead, shows that the diffuse aurora (as seen at a distance or close to the horizon) is likely to be made up of many faint rays, bands and other forms. Therefore a likely explanation is that the echoes similar to those of Figure 8 really come from such faint auroral forms.

The frequent correlation of the radio echoes with visible auroral forms as illustrated in Figures 5 and 6 can hardly be regarded as accidental. Thus it seems likely that the anomalous behavior demonstrated in Figure 8 is not the result of regions of ionization uncorrelated with visible auroral forms. Whether these anomalous echoes come from abnormally high visible forms or from faint diffuse forms of normal height cannot be decided from the information at hand.

Conclusion

It is therefore concluded that, contrary to the views of Harang and Landmark, "auroral radio echoes" come directly from ionization in the immediate vicinity of the visible auroral forms.

B. At Frequencies Above 100 mc

In view of the lack of a suitable research radar for the investigation of auroral echoes at a frequency above 100 mc, it was decided that use would be made, if possible, of signals from V.H.F. or U.H.F. transmitters operated in the vicinity by other agencies.

A careful search of the 100 mc to 1000 mc frequency band was made using an APR-4 search receiver and a variety of specially built antennas. These included a 200 mc ten element Yagi, a 6 turn helical antenna for 250 mc, and L band rhombic and an L band dipole array with reflecting screen. A series of transmissions were found and monitored, but none of them were found to be suitable for auroral propagation studies.

An attempt was therefore made to make auroral propagation studies utilizing a low power (10 watt nominal) crystal controlled transmitter supplied on loan by the U.S. Air Force authorities at Ladd Air Force Base. (A 100 watt equipment had been requested, but only the airborne 10 watt version was available.) Two ten-element Yagis stacked vertically one wavelength apart were set up on the roof of the Geophysical Institute, the array being directed at low elevation towards magnetic north. The receiver was located at a point approximately 15 miles (magnetic) east of College, and was coupled to a similar antenna also directed magnetic north. The receiver was adapted to drive a pen recorder and the antenna azimuths adjusted so that the leakage signal propagated direct from the transmitter via ground wave was about equal in strength to the receiver noise. The equipment was tested after the spring equinox, and shown to be capable of operating as desired. Calculations based on the 100 mc radar results showed that an aurorally propagated signal could be expected only during strong aurora; for this reason the equipment was switched off with the intention of recommencing operation during the September equinox, when strong aurora are more common than during the summer months.

In the meantime, however, a source of Government Surplus SA-2 200 mc radars has been found, and it is now planned to install one of these equipments instead. This is an ex-U.S. Navy radar, capable of 150 kw peak power for pulses of 3-5 microseconds in length. Such an equipment, after suitable modifications, should prove a most valuable research tool, enabling the frequency spectrum of auroral radar echoes (hitherto carried out at College on frequencies of 12, 25, 50 and 100 mc) to be extended by a further octave.

Task No. 3 Study of Propagation on an Existing Microwave Link

One end of this link is located at the bottom of a rather large valley, the other being situated roughly 25 miles away at the summit of one of the surrounding hills. The link is line of sight throughout. The antenna at the lower site consists of a parabolic reflector aimed almost vertically upwards at a plane reflector supported at the top of a tower. This reflector is so oriented that the radio waves from the paraboloid are reflected towards the distant receiving site. Here the radio waves are received directly on a similar parabolic reflector mounted on a short tower.

In order to monitor the signal strengths propagated in each direction across the link, voltages derived from the two receiver automatic gain control circuits were used to drive pen recorders. These recordings were calibrated once each week using a microwave signal generator applied to the input of each receiver.

Daily meteorological data was obtained from radio-sonde soundings made at a point approximately one mile from the path; some measurements were also made at the lower tower through the courtesy of an Ice Fog Research group working the vicinity. From these measurements it was possible to compute the effective index of refraction of the atmosphere and to obtain information on the size, intensity and long term duration of the atmospheric ducts.

Utilizing the meteorological data obtained at the lower tower, it soon became apparent that most of the winter-time ducts existing at the lower site were so close to the ground as to exclude the reflector situated at the top of the tower. The line-of-sight radio path between the plane reflector and the distant paraboloid therefore lay above the duct; hence it was not surprising that the signal strengths were apparently unaffected by the presence of ducts.

In order to increase the effect of the ducts, another reflector was installed on the tower at a considerably lower height. (The minimum usable height was limited by the desirability of avoiding obstruction by nearby buildings.) This lower path ensured that at least some of line of sight lay in the region where ducts occurred; even so, it was found that the effect of the ducts was less than the residual variations in recorded signal strength due to equipmental variations. If the signal were propagated along the duct to the foothills (where the duct will be terminated) and thence to the receiving antenna, the signal strength would drop seriously, due to arrival off the main lobe of the receiving antenna. Since no such decrease occurred, it must be considered that the mode of propagation is via leakage from the duct and is approximately along the normal radio path.

Conclusion

The conclusion therefore is that meteorological phenomena play a very small part on this particular link. This should not be regarded as surprising, in view of the relatively short path and the fact that the line of sight is inclined at an elevation of approximately one degree.

Task No. 4 To Study the Prediction of Auroral and Ionospheric Storms

A. Introduction

The prediction of a phenomenon implies knowledge of the behavior of that phenomenon. The aurora is only one phase or aspect of several terrestrial phenomena which appear to be directly related to activity on the sun. Neutral streams of ionized particles are emitted from the sun and due to the sun's rotation sweep over the earth. The exact sources of the particles are unknown, one theory placing the origin in the active areas of the sunspots and another in the spicules which appear near the poles of the sun; however, in this case, it is believed that the sunspots act as a control of the stream of particles.

The stream of ionized particles are trapped by the earth's magnetic field and caused to bombard the atmosphere in the polar regions. A series of phenomena result from this bombardment. The passage of the particles through the atmosphere excites the atoms and molecules to radiate light: - the aurora. At the same time many of the atoms and molecules are ionized thus producing a trail of electrons or perhaps bundles and/or sheets of trails of electrons which cause the radar echoes. The accumulated effects from the bombardment produce disturbances or irregularities in the comparatively uniform ionized layers of the atmosphere, resulting in what is called an ionospheric storm. The moving electrons and ions affect the electric currents in the atmosphere and are detected by two methods at the surface of the earth: (1) through the disturbances of the earth's magnetic field causing the magnetic storms, and (2) by induced currents in the earth producing the earth-current storms.

B. Solar Phenomena

The exact source of the stream of particles emanating from the sun, as mentioned above, is not known; however, the fact that a stream of particles from the sun reaches the earth is quite well established. Recent spectroscopic investigations of auroras by A.B. Meinel[15] at the Yerkes Observatory have shown that protons are entering the atmosphere, certainly during the earlier phases of the auroral display. Until the location of the source of the stream of protons is established, it is possible only to study terrestrial phenomena with respect to the various indices of solar activity. The earliest and most used index of solar activity is the sunspot-number. The sunspots themselves do not cause effects on the earth but merely a measure of solar activity. Searches for the solar phenomena which cause terrestrial disturbances are underway at several observatories. Solar flares are known to have direct effects by producing ionization at levels below the normal ionosphere and causing complete absorption of radio waves on the sunlit side of the earth. Likewise, certain features of the corona are closely related to terrestrial phenomena and systematic observations with coronographs are being made at Climax, Colorado, and at Sacramento Peak, New Mexico. Radio noise from the sun has been shown to be an index of solar activity. The radio noise of the centimeter range appears to come from the chromosphere, and its range in amplitude is considerably smaller than for the meter range. The available evidence points toward the origin of the radio noise in the meter range as discrete sources in the corona and that the major bursts of noise are connected with streams of particles traversing the solar atmosphere with high velocity.

It thus seems that the prediction of aurora and other phenomena initiated by a stream of ionized particles from the sun should be closely related to the bursts of radio noise in the meter range from the sun. It is hoped to use this technique near the end of the contract year.

C. Magnetic Storms

The morphology of magnetic storms is being investigated at the Geophysical Institute by Masahisa Sugiura under the direction of Professor Sydney Chapman. The work is sponsored by a contract with the Geophysical Research Directorate of the Air Force Cambridge Research Laboratory, Contract No. AF 19(604)-1048.

The analysis of visual observations of aurora, a summary of which is given below, points out the close relationship between the incidence of auroras and the K-index of magnetic activity. Also, the visual as well as the photographic observations indicate a close relationship with the fluctuations which occur during the disturbances in the magnetic field. The fluctuations are very important factors determing the value of the K-index of magnetic activity. Hence, we would expect that the K-index for a given place would give an indication of the presence of aurora; however, two things must be kept in mind, namely, the scale of the K-index values varies with the observatory, and also, that the influence of a magnetic disturbance is detectable much farther by a magnetometer than an aurora is detected by sight.

Both the K-index and auroras have a strong diurnal trend and since K-indices are available for some 55 stations distributed over the globe, it might be interesting to make a preliminary comparison of K-indices. The K-indices for the month of March 1953 were used to obtain the average daily variation of K for the following observatories:

	Geographic		Geomagnetic	
	Lat.	Long.	Lat.	Long.
Sodankyla	N67° 22'	26° 39'	N63.8°	120.0°
College	N64 52	212 10	N64.5	255.4
Heard Island	S53 02	73 22	S61.2	129.9
Macquarie Is.	S54 30	158 57	S61.1	243.1

The northern and southern observatories are each approximately the same geomagnetic latitude and separated in longitude by more than 90°. Also, the observatories form pairs which are as near as possible to the ends of geomagnetic field lines. The average variation of K with time of day is shown in Figure 10 in which the abscissa is GMT and the ordinate K-index. Local midnight is shown for each of the observatories. The similarity of the diurnal curves for the two stations at the ends of a geomagnetic field line is striking, even though there is over three hours difference of local solar time between each pair.

D. Ionospheric Storms

No specific studies of the ionospheric storms are being made at the Institute at present; however, routine ionospheric observations are being made on a contract with the National Bureau of Standards. The data are available and are being used in correlation studies with various phenomena, some of which are mentioned in this report.

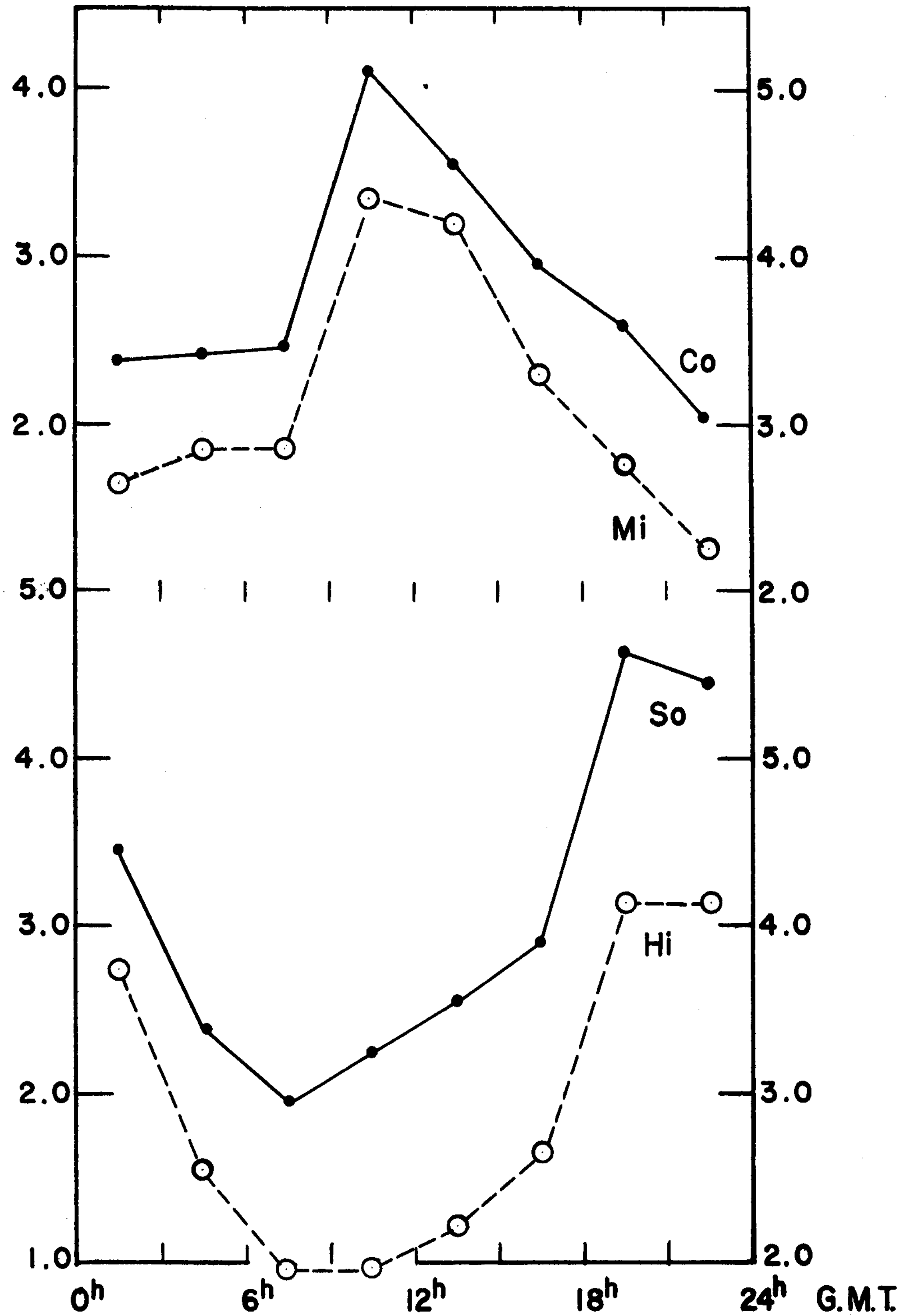


FIG. 10. AVERAGE K-INDEX

E. Earth Currents

The electric currents in the upper atmosphere with their associated magnetic fields disturb the steady magnetic field of the earth and also induce electric currents in the earth. The electric currents are readily measured, but precautions must be taken with respect to man-made disturbances. The disturbances of the earth currents (or earth-current storms) are probably of most interest in connection with studies of the aurora. On the other hand, the fluctuating earth currents may bear a significant relationship to the scintillation of the radio stars, since both are due to motions of ion masses in the upper atmosphere.

Records of the earth currents in the vicinity of College have been made during the past year. The studies have not been a part of a contract, and consequently only a minimum effort has been devoted to the study of the records. A preliminary examination of the earth current records and of the sequences of auroral photographs taken with the "all-sky" camera to be described later, show that disturbances in the earth currents begin at the critical phase in the development of the auroral display, that is, at the time a homogeneous arc "breaks up." A typical break-up is shown in Figure 5 in Appendix "A" of this report describing the "all-sky" camera.

Further investigations will be made of the earth currents in connection with auroras, especially since the literature records that "Stormer's auroral stations in Norway are regularly kept informed by the Telegraph Department of sudden commencement of disturbance in line communication so that the stations may be ready for making auroral observations."

F. Auroral Observations

1. Visual

The study of auroral displays has been made chiefly from visual observations, and during the last three years systematic observations have been made of auroras over Alaska in connection with Signal Corps Contract No. DA-36-039 SC-56739. The analysis of observations for the seasons 1951-52 and 1952-53 have been published[16] and for the season 1953-54 in Quarterly Progress Report No. 5, 1 March 1955 to 31 May 1955, on the above contract. Studies were made of the distribution of auroras as functions of geomagnetic latitude for various degrees of magnetic activity and of the frequency of auroras as a function of the time of night, for the several degrees of magnetic activity. During the observing season of 1953-54, a time of minimum sunspot activity, the frequency of auroras at the zenith for College was 2.5% of the time during the magnetically quiet periods, K equal 1 or 2. For K equal 2 or 3 the frequency was 10%; for K equal 4 or 5 the frequency was 22%; and during times of greatest magnetic activity, K equal 6 or 7 the frequency of zenith auroras was 52% of the observing time. It was pointed out in the analysis that the maximum frequency of auroras during the night is progressively later for the more southerly latitudes in Alaska. North of Point Barrow the maximum is approximately 2300 hours local time; at Point Barrow it is at midnight, while at College and Northway the maximum is approximately 0230 hours local time. The stations farther south are rather indefinite with the amount of data available, but it appears to be well after midnight.

The incidence of auroras was shown to be very closely correlated to the local magnetic activity, K-index, rather than the planetary index of magnetic activity, K_p; hence auroras in other localities will no doubt follow in the same manner.

The visual observations of auroras at several localities over Alaska have been used to construct synoptic maps at fifteen-minute intervals, thus showing the general development of an auroral display. Although this technique has certain advantages, a photographic record of the entire sky showing the distribution of auroras is extremely valuable, not only for the general development of the auroral display over the large areas, but if the exposures can be made at one-minute intervals, the detailed development of the display is permanently recorded and may be studied at leisure along with records of other geophysical phenomena.

2. Photographic

The "all-sky" camera, which is described in Appendix "A" of this report, has been used during the past year to maintain a systematic patrol of the sky as seen from College. A second camera was placed in operation at Point Barrow, and a number of records have been obtained at that place. The analysis of the photographs is being made at the present time.

Some preliminary studies were made of one of the interesting features, namely the "180°-bends" in arcs, either the homogeneous or rayed arcs. The "180°-bend" is formed when an arc is bent through an angle of 180° thus forming two parallel arcs. The bends are classified by the orientation of the bend, either with the open end of the bend toward the east or toward the west. All of the photographs from January 1954 to April 1955 have been examined, and 105 of the 180°-bends were found. The distribution with time of the bends oriented in the two directions is interesting and is shown in Figure 11. A definite maximum in the appearance of bends with the open end toward the west occurs at 2330 hours Alaskan Standard Time (essentially local time at College). A maximum in the frequency of the bends having the open end toward the east occurs at 0300 hours. This behavior of the arcs reminds one of the idealized system of electric currents in the ionosphere in the vicinity of the auroral zone(17).

A.B. Meinel and D.H. Schulte(18) report on the systematic motions of auroral features as observed with a sequence camera. Our data offer an excellent opportunity to check for motions of auroral features and if systematic effects are observed, the detailed measurements of the motions will be undertaken. Meinel reported that the drift of auroral features was westward only during the evening hours and the drift was observed to be always eastward during the morning hours. Of the 105 bends reported above, 30 of them were observed to move, 20 were observed to have westward drifts, and 10 were observed to have eastward drifts. The numbers to have drifts east or west are shown for each hour of the night in Figure 12. As may be seen we do not find a systematic division of the westward and eastward drifts into the evening and morning hours. The westward motions, however, were clustered around midnight (11:30 p.m.).

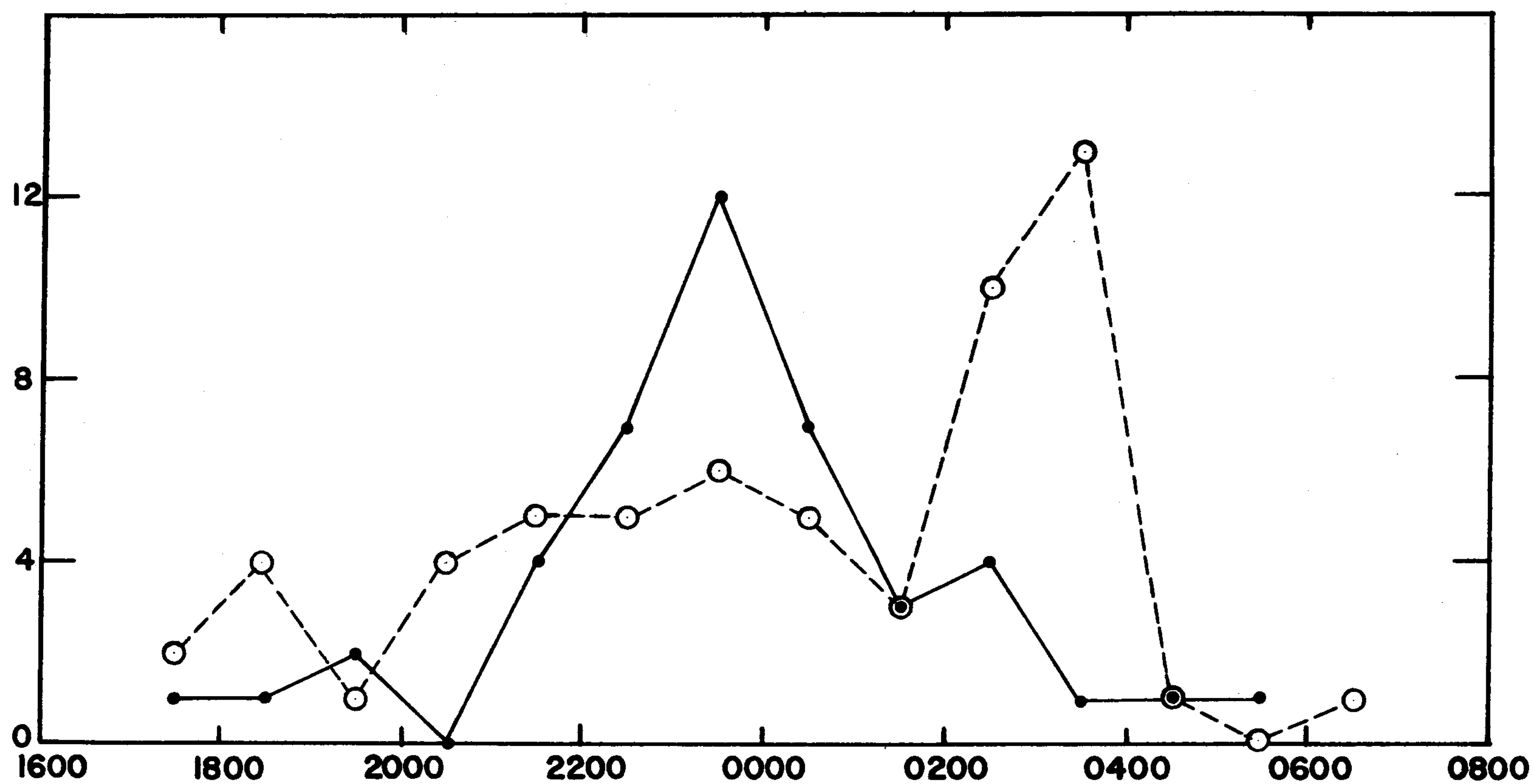


FIG. 11. NO. OF 180°-BENDS; CIRCLES ARE OPEN ENDS TOWARD EAST, DOTS ARE TOWARD WEST.

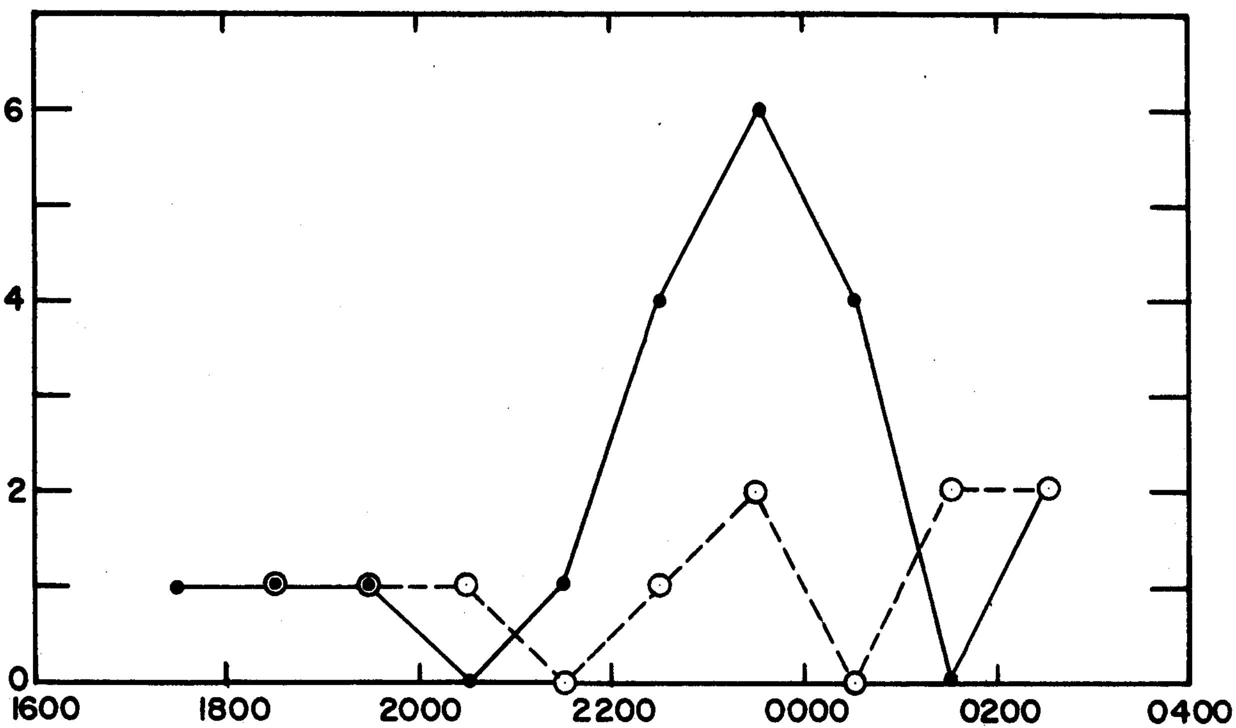


FIG. 12. DIRECTION OF MOTION OF 180°—BENDS; DOTS ARE WESTWARD MOTION AND CIRCLES EASTWARD.

3. Photoelectric

An examination of the films taken with the all-sky patrol camera shows very clearly the great changes in the overall brightness of the sky during the night, often without strong and well defined auroral structure. Since the amount of light emitted by the atmosphere is proportional to the exciting source, photometric observations should give an index of auroral activity, a technique which has been used by many observers. A simple photometer was set up to measure the total blackening of the film and thus give some measure of the total variations in light from the entire sky. Since the film had not been calibrated with a sensitometer, this method could give only rough variations of intensity; however, the variations in the amount of light are large, and rough measures will give significant results. In the meantime, two photoelectric photometers with continuous recording were installed to measure the illumination on a matte porcelain plate exposed to the sky. The photometers were equipped with interference type filters, one transmitting the green auroral line, 5577A, and the other the ionized nitrogen bands, 3914A. Records of the variation of intensity of the ionized nitrogen bands as well as the relative intensities obtained with the all-sky camera, are shown in Figure 13 for one night, March 30-31, 1955. The amount of absorption of the extra-terrestrial radio noise at 30 mc with an antenna pointed toward the zenith is shown for the same period of time. It is very obvious that there is a close relationship between the amount of absorption of radio signals and the intensity of auroral light. It is to be expected that the exciting source not only causes

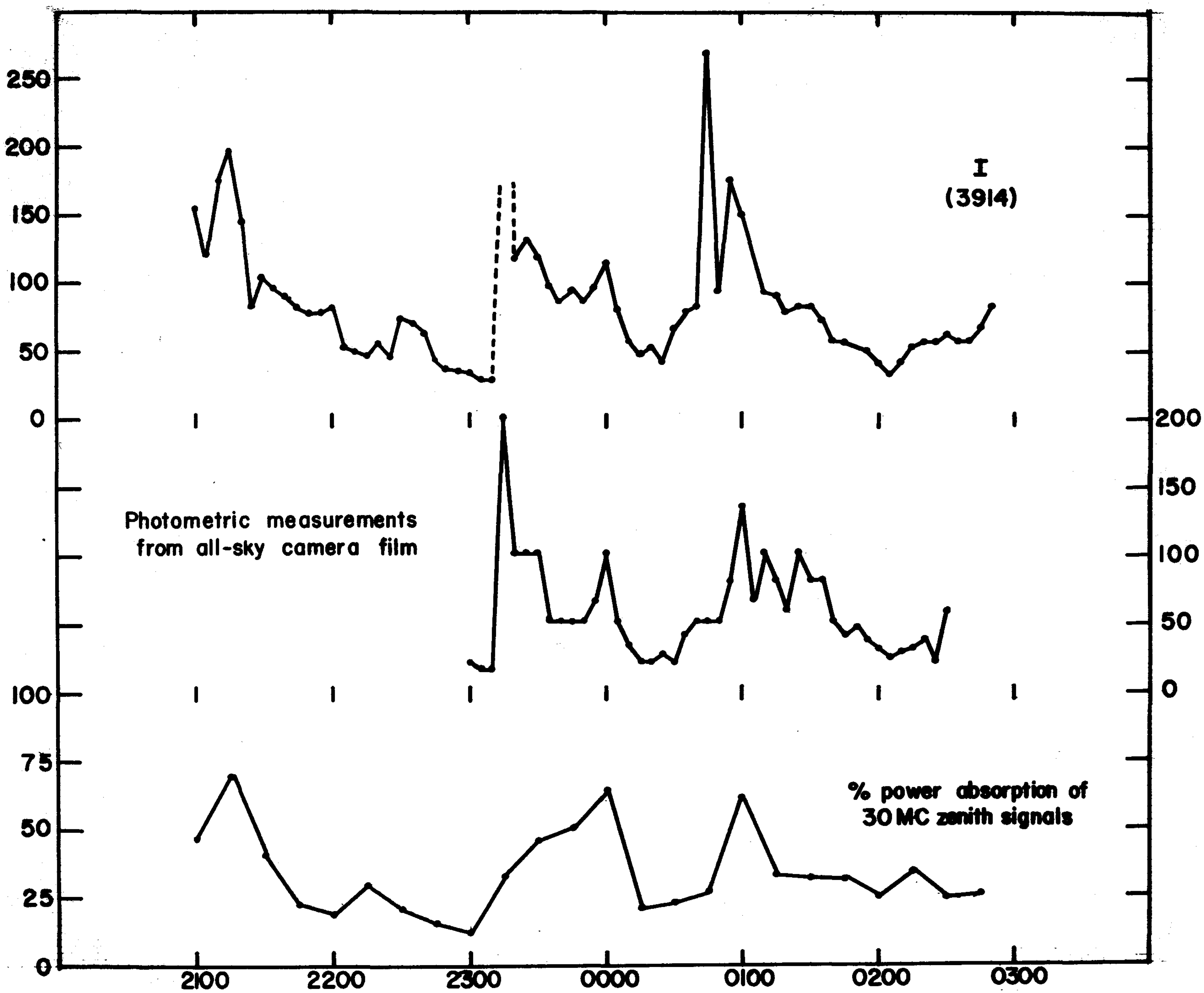


FIG. 13. COMPARISONS FOR MARCH 30/31, 1955

the atoms and molecules of the upper atmosphere to radiate the aurora but ionizes the atoms and molecules, producing the absorption of the radio waves.

Studies have been made comparing the intensity of auroral light with the records from the ionospheric recorder, type C-3. The results for the same night, March 30-31, 1955, are shown in Figure 14. The upper portion of the diagram shows the curve of intensity of the ionized nitrogen bands and the lower portion of the diagram shows fEs, the maximum frequency of the echo received from the E-region and Fmin, the lowest frequency of any echo observed. Again the relationship between the intensity of the auroral light and the absorption, Fmin, and the degree of sporadic ionization is shown.

The correlation between the intensity of the auroral light and the sporadic ionization for the period March 18-31, 1955, is shown in Figure 15, which compares the mean nightly values of auroral light and the maximum frequency of the Es echo. Again, the intensity of auroral light is directly related to the degree of ionization in the sporadic E.

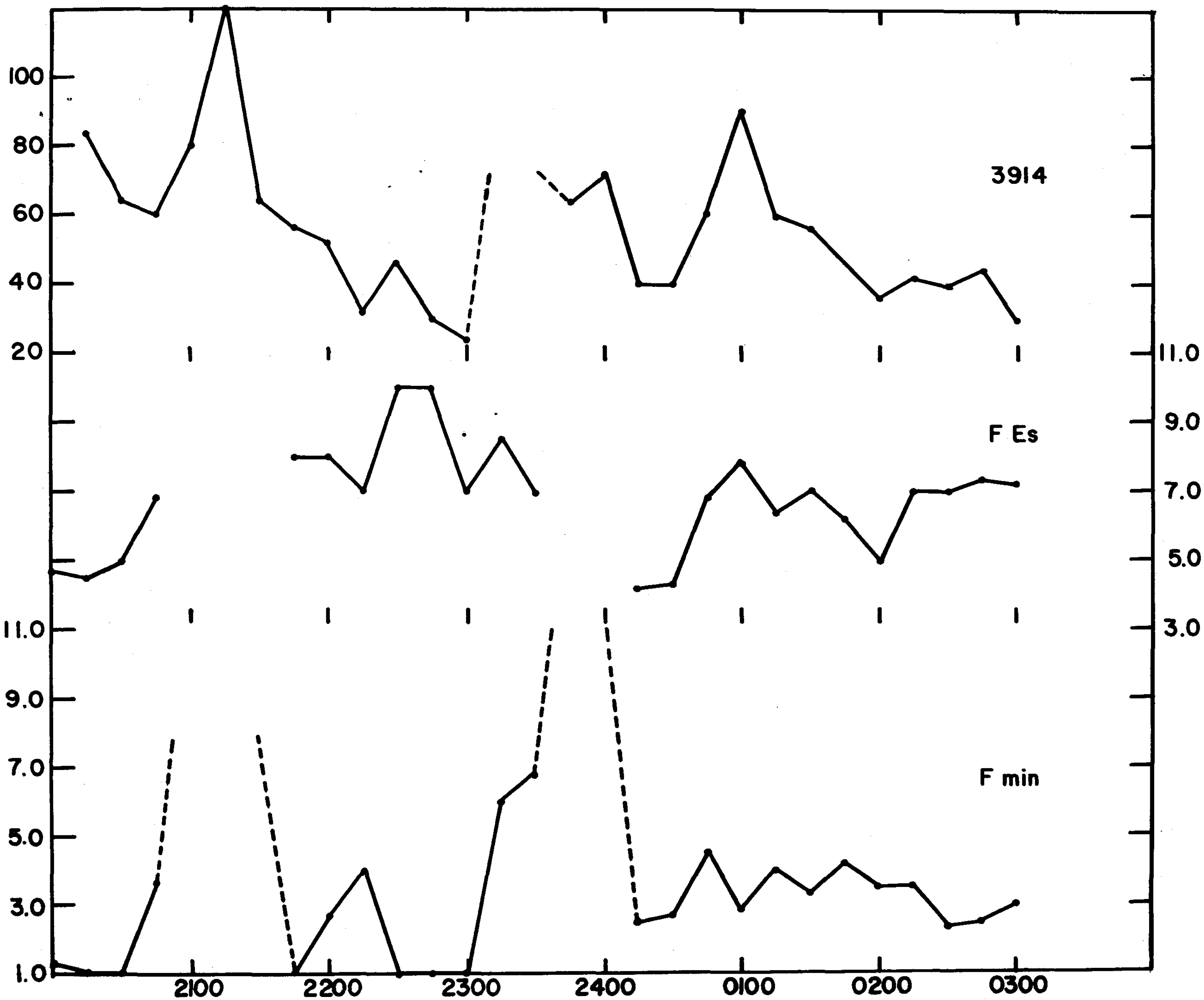


FIG. 14. COMPARISONS FOR MARCH 30/31, 1955

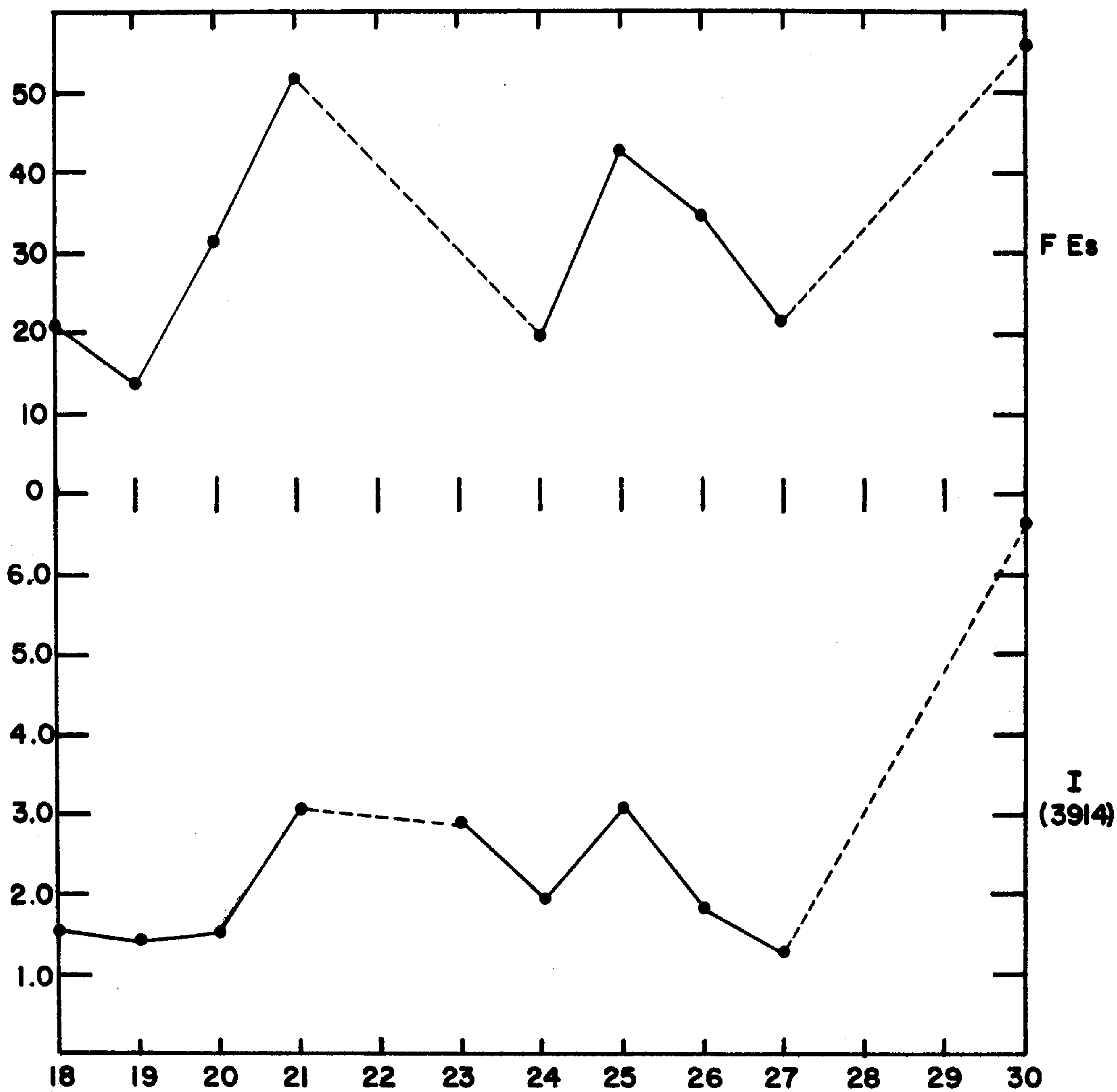


FIG. 15. MEAN NIGHTLY VALUES OF MARCH, 1955

Task No. 5 To Study "Whistlers"

Audio frequency electromagnetic phenomena known as "whistlers" have been observed by various investigators since they were first reported by Barkhausen[19] in 1919. These whistlers are characterized by a descending tone starting at about 10,000 cycles per second and terminating somewhere between 1,000 and 500 cycles per second. A promising theory regarding the nature of whistlers was described by L.R.O. Storey[20] in 1953. In this paper it is shown that for the low frequency components of a pulse, the index of refraction for an ionized medium is a minimum along the direction of the earth's magnetic field. Thus it is supposed that some of the energy of a pulse originating from a lightning discharge is constrained to follow the lines of the earth's magnetic field. Some of the energy is reflected by the earth back along the same path to the area of the lightning flash. Having traveled a distance of the order of 80,000 kilometers, through an ionized medium, the pulse suffers considerable frequency dispersion.

The high frequencies arrive before the low frequencies due to their higher velocity of propagation. The dispersion of a whistler is shown to be represented by the equation:

$$t = \frac{D}{f^{\frac{1}{2}}}$$

where t is the time of occurrence of a particular frequency f and D is constant for a particular whistler known as its dispersion. Other factors being constant, D is proportional to path length. Thus it is evident that whistlers originating from discharges in the southern hemisphere will have dispersions of the order of one half of those originating in the northern hemisphere. This ratio is shown experimentally to be the case.

It is apparent, then, that since the magnetic lines of force are longer at high geomagnetic latitudes than those at low geomagnetic latitudes, the dispersions of whistlers observed at high latitudes should be greater than those observed at the latitudes of Cambridge, England, and other middle latitude stations. Thus it appears that it is desirable to make an attempt to observe whistlers at College, Alaska, which has a geomagnetic latitude of the order of 65°. Table II lists the approximate path lengths for various observing sites.

Table 2

Approximate Length of Geomagnetic Field Line Above Earth's Surface As A Function of Geomagnetic Co-Latitude

Place	Geomagnetic Co-Latitude (degrees)	Path Length (Km)
Barrow, Alaska	21.4	120,000
College, Alaska	25.3	84,000
Cambridge, England	35.2	40,000
Corvallis, Oregon	39.5	30,000
Stanford, California	45.0	22,000

Several attempts were made to observe whistlers near College, Alaska, during the latter half of 1953 and during 1954. However, no whistlers were observed during these attempts. It is now thought that the reasons for this failure are:

1. The antenna used was not adequate in that its d.c. resistance was too large.
2. The matching between the loop and amplifier was poor.
3. No tape recorder was used.
4. Lack of personnel prevented a large amount of listening time, especially during the interval between 2400 and sunrise, a period which has been shown to be most favorable for whistler reception.

During June 1955 the installation was modified to conform more exactly to that used by Stanford University and by Mr. Pope at Oregon State College during the spring of this year.

Figure 16 is a block diagram of this installation. The antenna is a single turn loop consisting of 3 parallel lengths of #12 copper wire. It is in the form of an isosceles triangle 30 feet high having a base of 60 feet. This loop is coupled by a special transformer to the U.T.C. So-1 transformer contained in the amplifier. The d.c. resistance of the loop is less than 0.1 ohm. Calculations show that a greater signal to noise ratio results from a large loop with few turns, than with a small loop having many turns. This loop is orientated such that the a.c. pickup is a minimum.

The amplifier is similar to that designed at Stanford University for a portable atmospherics detector[21]. Figure 17 shows the circuit diagram of this unit, and Figure 18 shows its frequency sensitivity curve. This amplifier is battery operated to minimize noise. It is

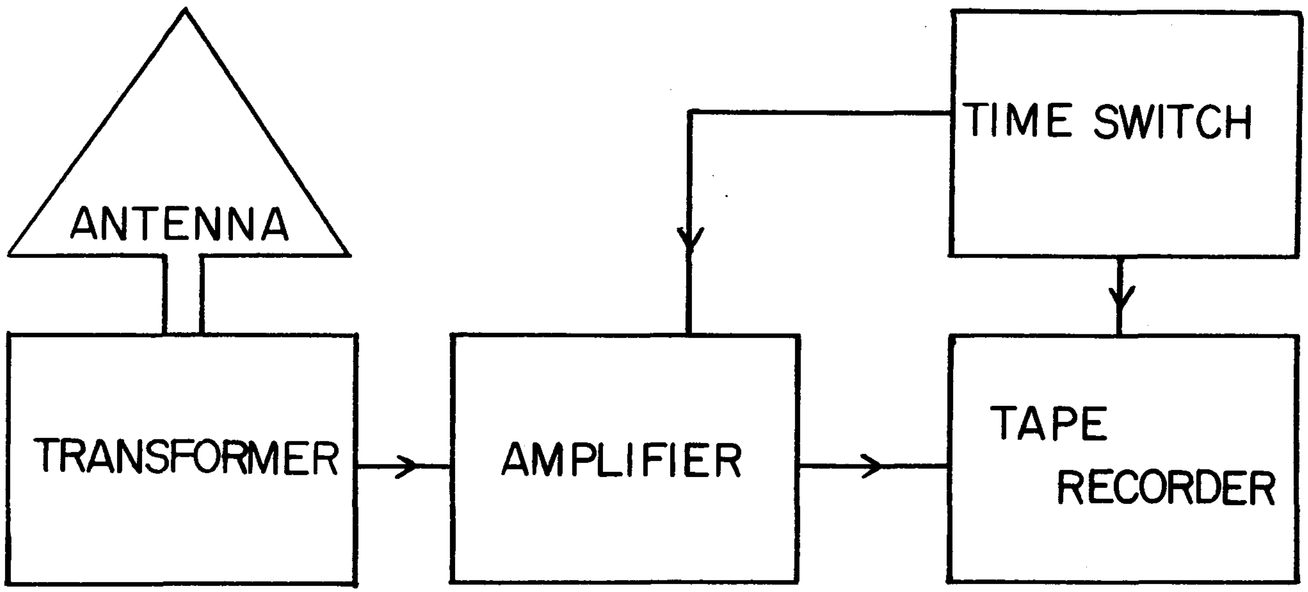


Figure 16   Black Schematic of Whistler Recording Equipment

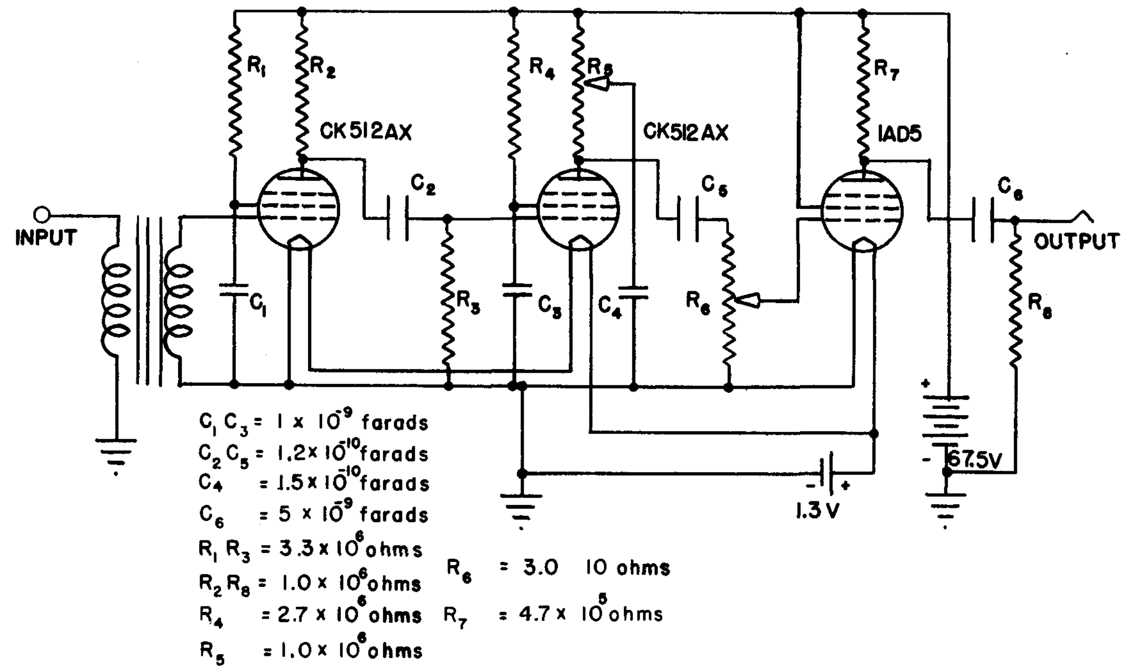


Fig 17 SCHEMATIC DIAGRAM OF AMPLIFIER

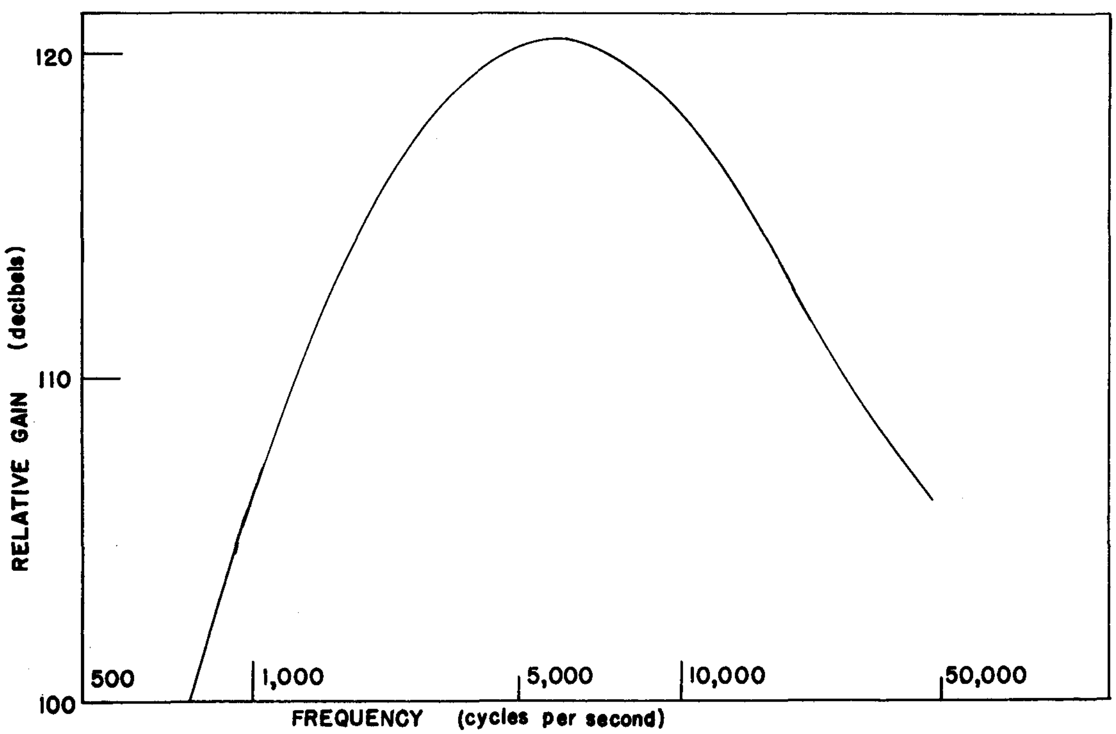


Fig 18 SENSITIVITY CURVE OF AMPLIFIER

located at the base of the loop, a 100 foot length of shielded cable being used to transfer the signal to an a.c. tape recorder.

The recorder which was used for the preliminary observations made between July 1, 1955, and July 10, 1955, was an Eicor Model 15, borrowed from the University of Alaska. This recorder was not designed for scientific observations and is to be replaced by a more satisfactory model. A time switch was arranged to turn the apparatus on automatically at a preselected time. The time of start was selected as 2400, the tape lasting for 45 minutes. One run was made per day.

Table 3 shows the results of these preliminary observations between July 1, and July 10, 1955. It is to be noted that on two occasions whistlers were recorded. The dispersion of the 35 whistlers recorded on July 3 appear to be 2 or 3 times as great as those measured at Oregon State College. A number of these whistlers have been selected and will be sent to Stanford University, where an audio spectrograph will be used to make accurate measurements of the frequency dispersion.

Table 3

Results of Whistler Observations Between 1 July 1955 and 10 July 1955

Date	No. of Whistlers	Approx. Time of Start of Run	Approx. Time of End of Run
1 July	3	2400	2445
4 July	None	2400	2445
9 July	35	2400	2445

Conclusion

It is believed that these are the first observations of whistlers at high latitudes, and also that this is the first indication of a variation of frequency dispersion with latitude.

It therefore seems worthwhile to continue studies of whistlers at this location. It is intended that a systematic series of observations be made to determine the frequency of occurrence of whistlers at College, and their frequency dispersions, in order to make comparisons regarding these parameters with data recorded at other stations. For this purpose a Magnacord recorder has been ordered. Routine observations will be commenced when this equipment arrives.

Other Work

A. V.H.F. Communication Link

In April 1954 the Geophysical Institute was approached by the U.S. Air Force 11th Air Division H.Q. for assistance with a V.H.F. communication link, on which frequent outages were being reported. Two investigations were made, the first being to confirm that the communication failures were due to tropospheric effects, and the second to determine whether any improvements could be made by installing low noise preamplifiers at the receivers.

1. Investigation of Cause of Fade-Outs

Esterline Angus pen recorders, with specially built d.c. amplifiers, were installed at each end of the link concerned and used to monitor the received signal strengths. (Slightly different frequencies were used in the two directions.) Figure 19 shows a consecutive sequence of daily records taken during the period May 14-20. The receiver output was such that the pen deflection tended to saturate at high input strengths. As a result a 10 db change in signal strength had very little effect on the pen deflection, unless the signal was low. The recorder showed that weak signal strengths and severe fading were very common during the summer afternoons, and that the propagation was usually very good in the early morning hours, suggesting a tropospheric origin for the fading. This suggestion was confirmed when the twice daily radio-sonde data, taken at one end of the link, was analyzed (utilizing the methods described in Technical Paper No. 2 of the Air Defense Command Forecast Center, 3rd Weather Group, Ent Air Force

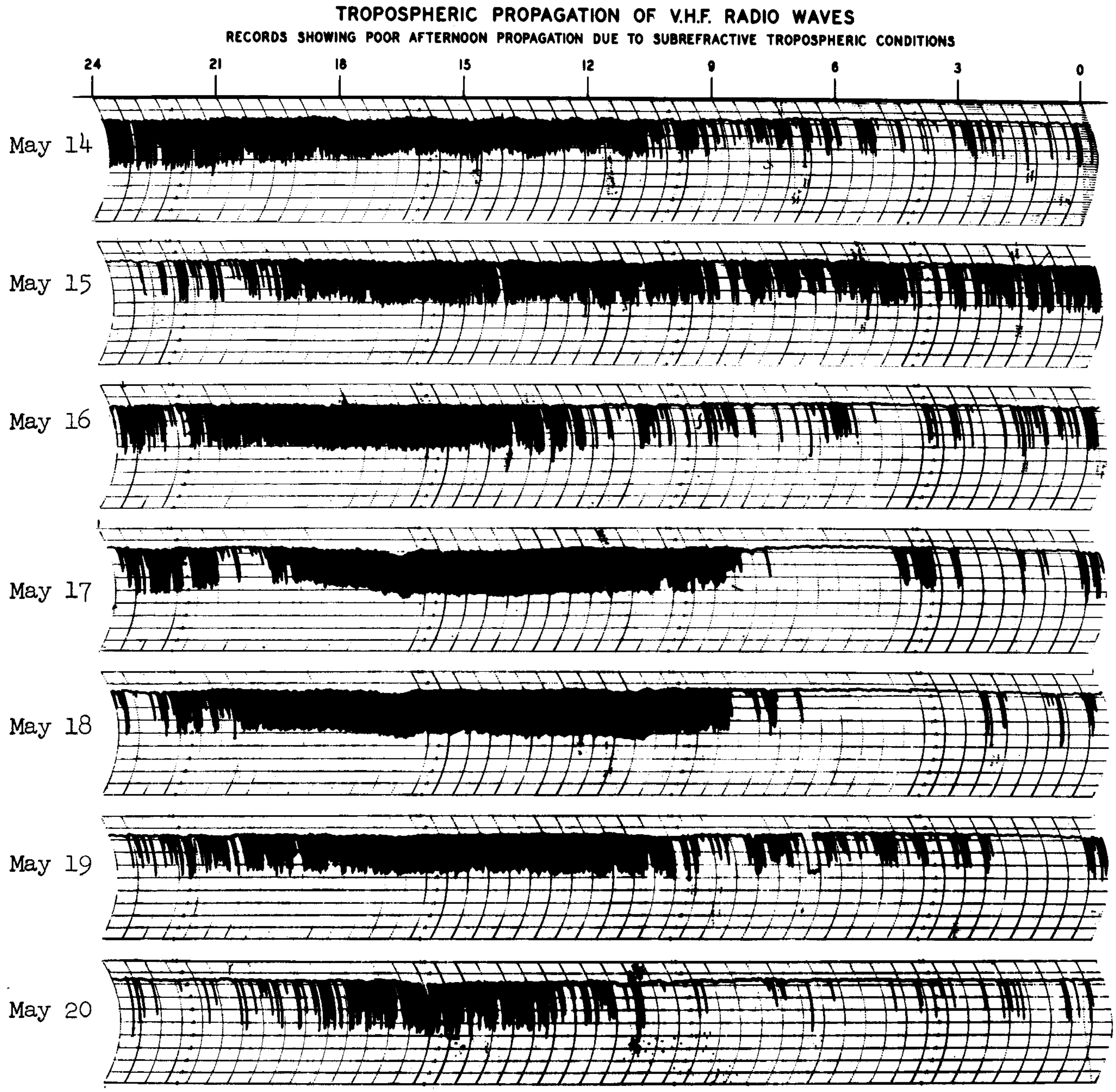

TROPOSPHERIC PROPAGATION OF V.H.F. RADIO WAVES
RECORDS SHOWING POOR AFTERNOON PROPAGATION DUE TO SUBREFRACTIVE TROPOSPHERIC CONDITIONS
24
21
18
15
12
9
6
3
0
May 14
May 15
May 16
May 17
May 18
May 19
May 20

Figure 19

Base, Colorado Springs, Colorado) to determine the variation of atmospheric (radio) refractive index with height. The average B profiles for 0500 AST and for 1700 AST for the period May 14-20 are reproduced in Figure 20 and show the presence of a night-time super refractive layer which is dissipated by convection during the afternoon to cause substandard conditions. (In a standard atmosphere, the B curve is a vertical straight line; any deviation of the line towards the left indicates increased bending of the rays downwards. Such bending tends to compensate for the curvature of the earth's surface, and usually results in improved radio wave propagation to a point beyond the horizon; on the other hand any decreased bending and positive slope for the B profile indicates substandard propagation.)

This investigation therefore showed that the fading was due to tropospheric phenomena, rather than to equipmental or personnel failure.

2. Improvement of Receiver Noise Factor

The second approach to the problem was to consider the possibility of improving the noise factor of the receiver, and hence its sensitivity. Two of the receivers were supplied to the Institute for test, and gave noise factors, after careful alignment of between 8 and 9 db. The receivers used standard V.H.F. pentodes as input tubes, and it was therefore felt that a significant improvement could be made by using a low noise cascode circuit (see reference No. 22). Figure 21 shows the actual circuit diagram used, and Figures 22a and 22b show the assembled preamplifier. A brass chassis was used, and considerable care was taken in the selection and layout of components in order to

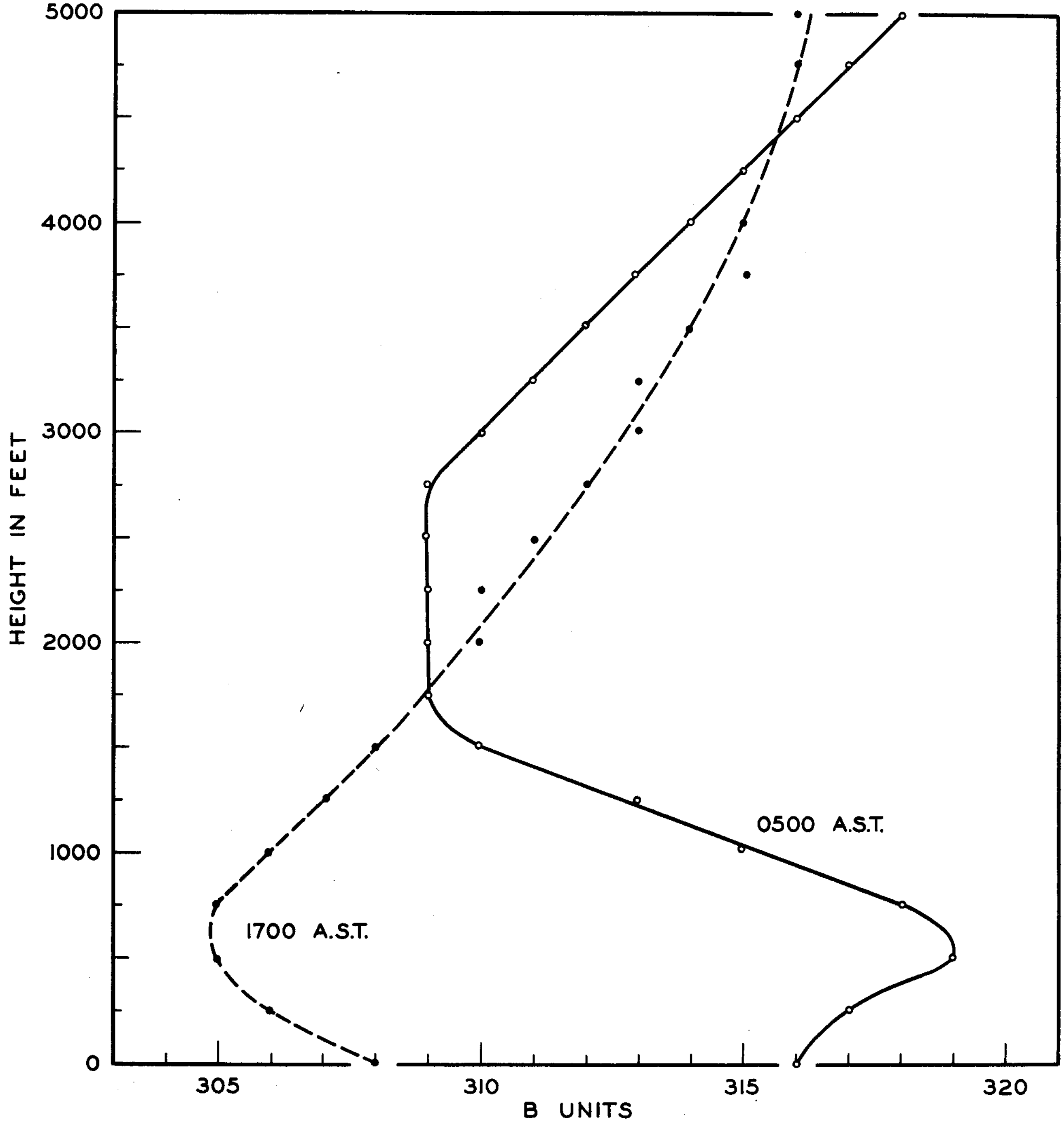
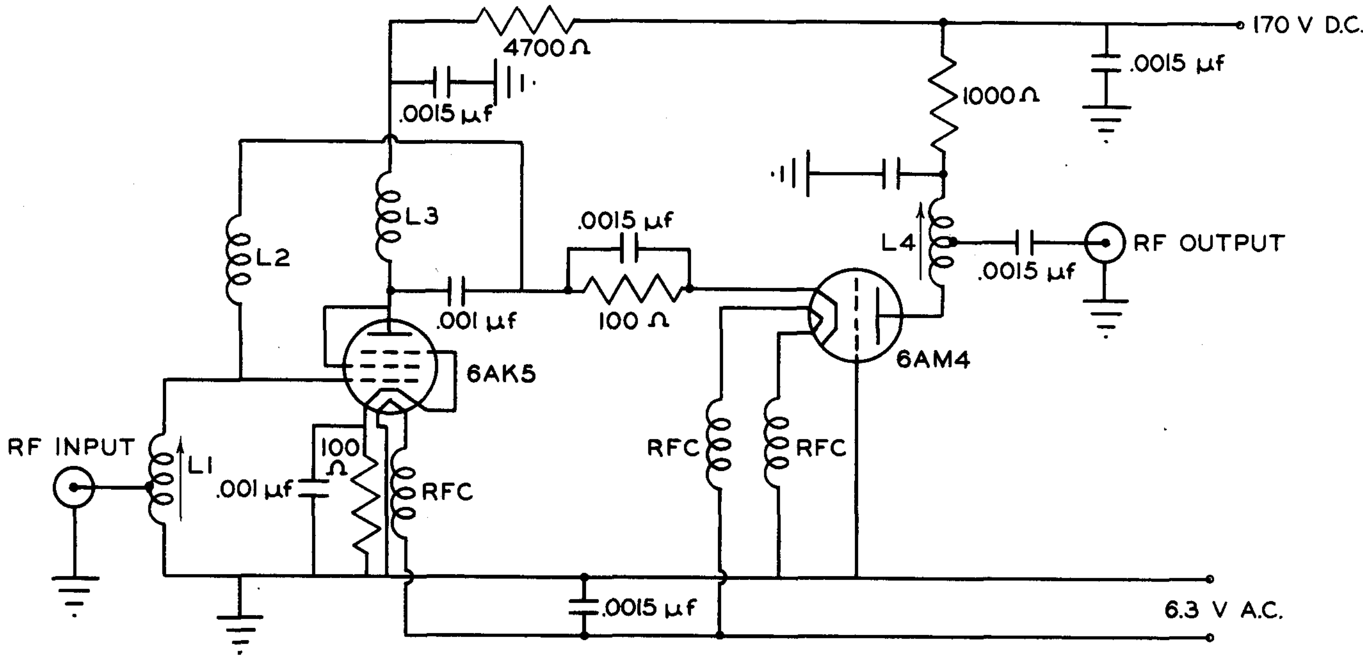


FIG. 20 AVERAGE MORNING AND AFTERNOON B CURVES FOR RECORDS SHOWN IN FIG. 19



L1	15 turns #16 Copper ½" diameter, tapped 4 times from ground
L2	23 turns #18 Copper ½" diameter
L3	6½ turns #16 Copper 5/8" diameter
L4	9 turns #16 Copper, tapped 6½ times from anode
R.F.C.	9 turns #20 Copper, cotton covered, ½" diameter, close wound

Cambridge thermionic type LS7 coil forms with H.F. slugs were used for L1 and L4. All other coils were self supporting.

Figure 21 Circuit Diagram of V.H.F. Cascode Preamplifier

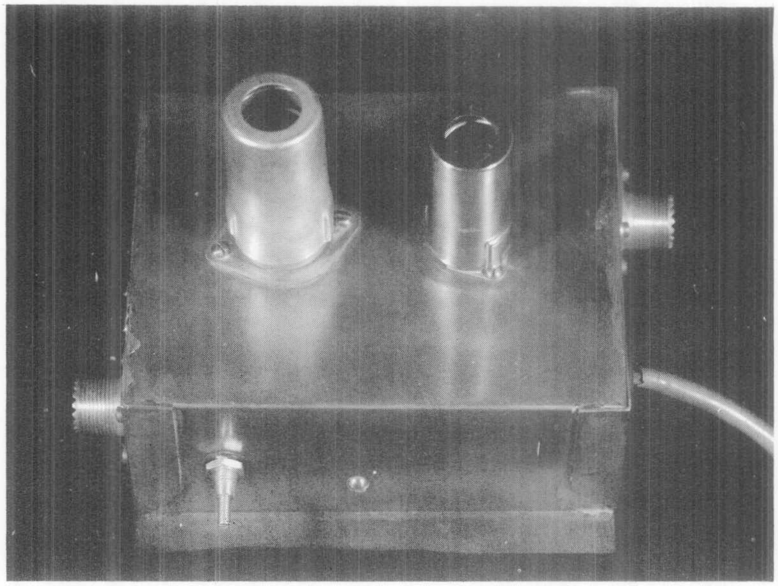


Figure 22(a)

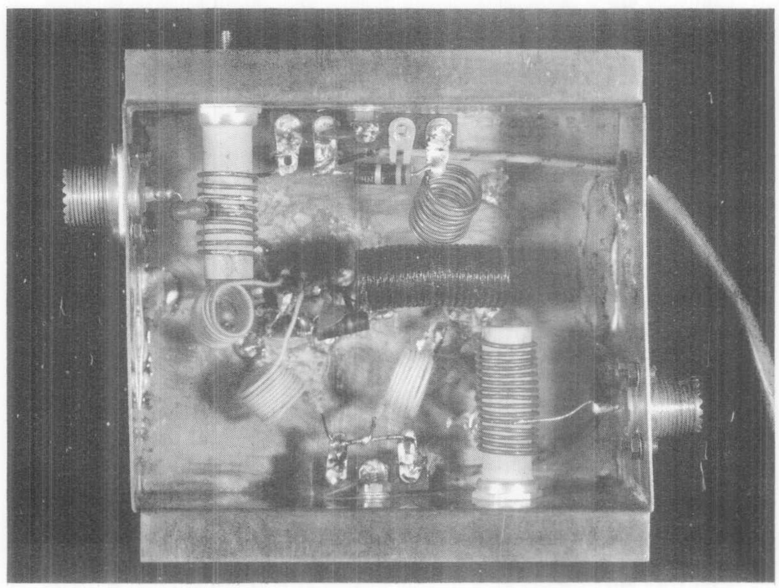


Figure 22(b)

Figure 22 V.H.F. Cascode Preamplifier

obtain high Q circuits and a low noise factor. The final operating characteristics of the preamplifier were:

Operating frequency	About 80 mc
Noise factor	4.5 db
Bandwidth	1.0 mc
Overall voltage gain	~ 60
R.F. input impedance	50Ω
R.F. output impedance	50Ω

Slug tuning of the tapped input and output coils enabled the preamplifier to be tuned to the required frequency.

This performance shows that the preamplifier gave a noise factor about 4 db better than the unmodified receiver. However, the value of this improvement depends upon whether the noise in the output of the receiver is due to local man-made interference rather than to receiver noise, and also in part on the nature of the signal fade-outs. The preamplifier was therefore installed on a local V.H.F. link, and its performance compared during the fades with that of an unmodified receiver operating simultaneously on the same link. This comparison was undertaken for several days by the military personnel normally using the link, in order to get a satisfactory impression of its performance under field conditions. These results showed convincingly that the signal from the receiver with the preamplifier was appreciably easier to read during many of the fades than that from the unmodified receiver. Both receivers, however, showed some complete fade outs, and in the opinion of the field engineer, the addition of a separate preamplifier requiring its own power supply and tuning, would be likely, under field conditions, to add as many new difficulties as it solved.

Conclusion

This work was therefore terminated with the conclusion that the signal outages were due to tropospheric fading, and that a significant improvement to the receiver noise factor (equivalent to at least doubling the transmitted power) was available by using the cascode preamplifier. However, it would be desirable that the preamplifier be constructed with its own power supply and that provision should be made for periodic checks of its noise factor by experienced personnel. The use of spaced receiving antennas (diversity reception) was also suggested, but no experiments were carried out, owing to lack of equipment and manpower.

B. Diffraction of V.H.F. Radio Waves by Mountains

In the summer of 1954 it was reported that commercial television signals from Anchorage, Alaska, were being received 210 miles to the northwest, at Lake Minchumina. The line of sight between the two stations passes over a 12,000 foot ridge of the Alaska Range at a point 135 miles from Anchorage and 75 miles from Minchumina; therefore, it seems clear that the signals are propagated by means of diffraction. Mt. McKinley (20,269 feet) and Mt. Foraker (17,000 feet) lie on opposite sides of the line of sight, separated by about 15 miles (see Figure 23).

A qualitative survey of the signal intensity in the vicinity of Lake Minchumina was made in the late summer of 1954. As this area is remote and inaccessible by land during the summer, it is necessary to transport all equipment and personnel by air. For this reason the higher of the two television channels (Channel 11, 200 mc) was chosen for the tests, in order to have more compact and manageable antennae. Channel 2 (57 mc) is also received at Minchumina, though these signals have not been studied.

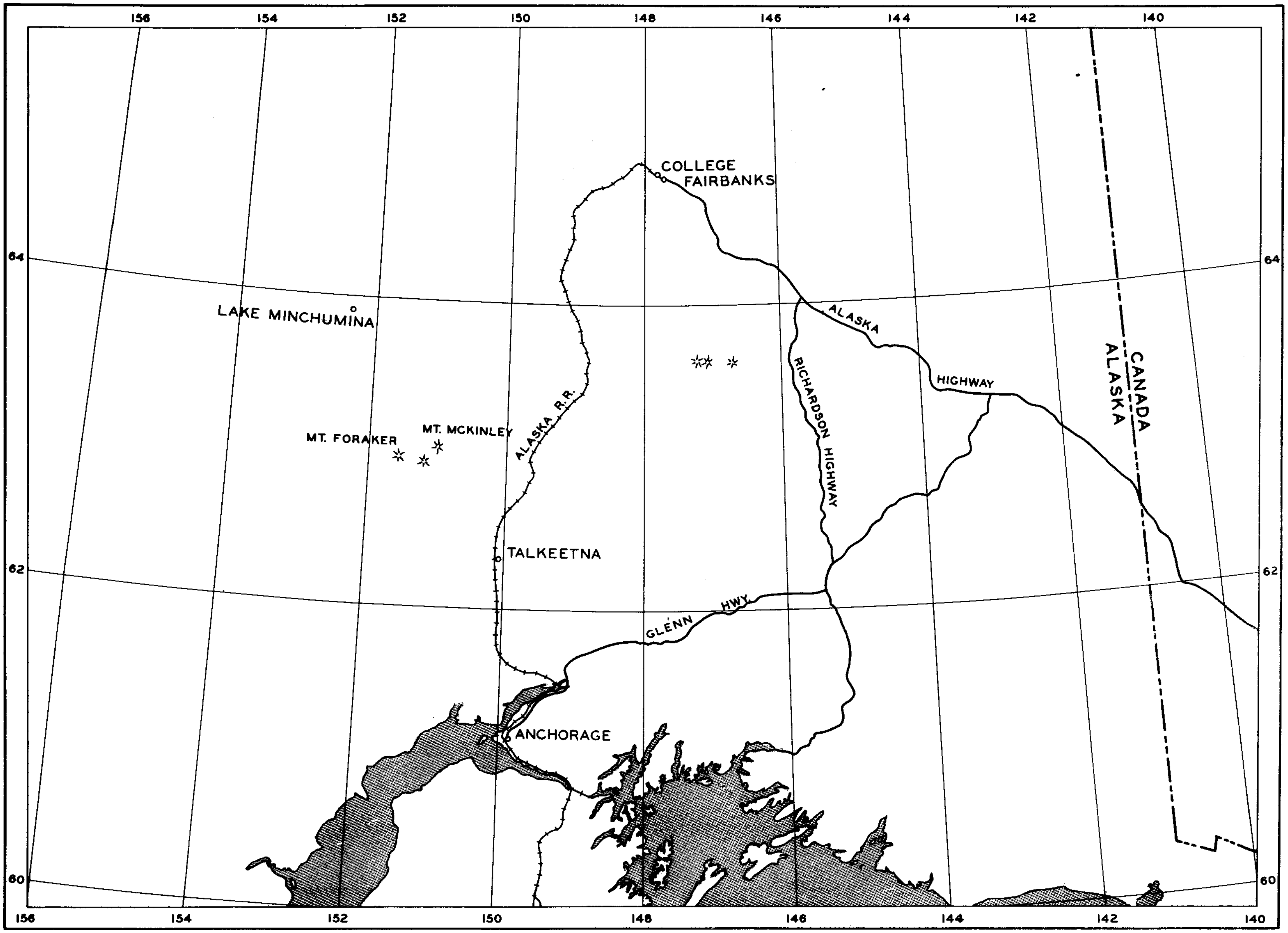


Figure 23 Map showing location of Anchorage - Lake Minchumina
V.H.F. Mountain Diffraction Link.

The equipment used on this preliminary survey consisted of an AN/APR-4 receiver with a commercial television preamplifier, and an eight-element Yagi antenna on a portable tripod. For direction finding a pair of Yagis was used, fed 180° out of phase. The equipment was transported about the Minchumina area in a light airplane equipped with floats.

It must be emphasized that the results obtained are only qualitative; however, they are of interest in that they indicate significant departures from past experience with diffracted signals.

Relative intensities of the incoming signals were determined by recording the readings of the diode current meter on the receiver and comparing with a calibration chart prepared with the aid of a standard signal generator. As the detailed characteristics of the antennae were unknown, and as the effects of ground reflections could not be determined, it was not possible to convert these relative values into absolute intensities.

The transmitter (Channel 11, KTVA) radiates a peak video power of 460 watts and a carrier power of 230 watts on the audio channel. Antenna height is 330 feet above mean sea level, antenna power gain is 7, and the horizontal pattern is uniform.

On July 6, 1954, the receiving equipment was set up next to the R.H. Collins' residence at the airport. As in all subsequent cases, no attempt was made to achieve optimum height of antenna above ground for lack of adequate masts. In each case, though, the site was chosen so as to look across a lake or pond in the direction of the mountains.

With this first setup it was determined that the angle of arrival of the signal was 160.4°, true, and the relative signal voltage was 1. The relative receiver noise with antenna connected is about 0.3. Later, the equipment was moved to the beach, about 150 yards toward the mountains from the previous site. The signal strength declined to a relative value of 0.53 but the bearing remained the same. All subsequent measurements at the airport were made from this location. The decrease in signal voltage undoubtedly was caused by the difference in elevation above the lake. Optimum antenna height, assuming the lake to be a perfectly conducting plane and the signal to be arriving at 2° elevation, is about 35 feet. The beach site provided antenna heights of from 6 to 12 feet above the water. The vertical angle subtended by the ridge between Mts. Foraker and McKinley is about 2°.

The vertically polarized component of the signal was not of measurable strength. Further measurements from the beach site on subsequent days gave signal voltages varying slightly about the value above. More significantly, the directions of arrival varied from 148° to 160° while the true bearing of the transmitter from this site is 156.5°. Although the direction-finding antenna was hastily improvised, it checks the results obtained with the 10-element Yagi, and it is certain that the results are accurate to within a degree. The conclusion is that the direction of arrival at Minchumina varies from day to day. Some of the bearings fell between Mt. McKinley and Mt. Foraker, but an equal number fell to the west of Foraker. Possibly the location is such that some variation of meteorological conditions could cause variation of the relative magnitudes and/or phases of two or more interfering waves, thus causing a swing in the apparent direction of arrival of the resultant wave.

On July 7, the equipment, excluding d.f. antenna, was taken to the beach at "Bilberg's cabin," occupied by "Slim" Carlson, about 4 2/3 miles east of the airport site. The signal here was weaker than at the airport, with a relative value of 0.35. The direction of arrival was 160°, so that the signal appeared to come from halfway between Mts. McKinley and Foraker. The height of antenna above water was about the same as at the airport.

On July 8 the equipment, including d.f. antenna, was taken to a point two miles west of the airport, where the antennas were mounted on a bank about 20 feet above the water. The relative signal voltage was 2.1 and the angle of arrival was 154°, the signal appearing to come from the east shoulder of Mt. Foraker. From this site the direct line to the transmitter passes directly over the summit of Mt. Foraker. The equipment was then moved to a point about five miles south of the previous site. At this point the relative signal voltage was 1.05 and the bearing was 146.4°. The signal apparently originates on the ridge halfway between Mts. Foraker and McKinley. This site, also, is on the extension of the line between the summit of Mt. Foraker and the transmitter. The site is not as high as the previous one, and the horizon is obscured by trees.

On July 9 readings were taken at the northern shore of Lake Tukomina, 10 miles southwest of the airport. The true bearing to the South Peak of McKinley is 135.4° and to Foraker is 146.4°. The signal bearing (with the 10-element Yagi) was 153.4°. The direct line to the transmitter passes about two miles to the west of Foraker's summit. The relative signal strength was 0.72, and the antenna height was about 25 feet above the lake. The d.f. antenna was not used.

Next, the equipment was moved to the north corner of L. Chilchukabena (Starr's Lake), 25 miles east of Minchumina airport. Antenna height was about 15 feet above the water. The far horizon was obscured by a low hill 2 miles away. The direct line to the transmitter passes over the North Peak of McKinley. The maximum relative signal strength was 2.75 and the true bearing was 166.4°, from a point high on the west shoulder of McKinley's South Peak. At this point the signal strength appeared to fluctuate, an effect not noticed elsewhere.

From qualitative observations made with Mr. Collins' television receiving equipment it was noted that Channel 2 and Channel 11 were received with substantially equal quality. The F.M. audio signals were of excellent quality while the A.M. video signals were quite noisy. On one occasion the Channel 11 audio faded out completely for an hour while the video was not noticeably affected.

From the rather scanty data acquired in this preliminary experiment it seems safe to conclude only the following:

(1) Maximum signals were obtained when the line of sight from the transmitter passed over either of the two largest mountains.

(2) There is some tropospheric meteorological influence involved.

(3) The diffraction phenomena involved are complicated but susceptible of experimental analysis.

(4) Signals received are of greater intensity than could be expected without the "obstacle gain" produced by the mountains.

The situation offers exceptional promise for experimental verification of the theory of diffraction by terrain obstacles. The signals are propagated over the highest mountain range in North America; the range is discrete, without extensive foothill systems; the valley to the north of the range is vast in extent and extremely flat. Numerous lakes and rivers offer facilities for transport by boat or airplane. The region is free of man-made radio noise and reflecting obstacles. There would be no necessity for obtaining permission of landowners and no problems of trespassing.

Following the preliminary survey described above, it was decided to instal a semi-permanent observatory at the R.H. Collins' residence at Lake Minchumina in order to obtain more extensive records of signal strength and direction of arrival. This equipment consisted of an AN/APR-4 receiver with a cascode preamplifier, and used a Yagi antenna, to monitor the signal strength by means of an Esterline-Angus pen recorder. In order to determine the direction of arrival of the signal a stearable beamed array was also used. This array consisted of eight five-element Yagis arranged in two bays of four, the bays being fed 180° out-of-phase to give an extremely sharp null. The array was mounted on a motor-driven rotator, and a servo-repeater system indicated the direction. A voltmeter connected to the A.V.C. bus of the household television receiver served as null indicator. Mr. and Mrs. Collins proved to be capable observers and are to be commended for their careful collection of data.

At present the data taken during the winter and spring of 1954-55 are being analyzed. At the time of this writing two observations can be made concerning the diffracted waves arriving at Lake Minchumina. First, there is a considerable variation in signal strength with periods of the order of an hour. Second, there are infrequent instances of a shift in the angle of arrival of the signal, of as much as ten degrees from the true bearing of the transmitter. These shifts are accompanied by severe fading of the signal, sometimes of a frequency-selective nature, so that the video signal may fade out and the audio remain fairly strong, and vice versa.

As these phenomena are unexpected, it is planned to investigate them more carefully using improved equipment. The modulation of the television transmitter makes it difficult to determine precisely the trend of signal strength; therefore, it is planned that a transmitter will be maintained in Anchorage for the exclusive purposes of the investigation. Two transmitters have been supplied by the Air Force; unfortunately they have a rated duty factor of only 17%, which makes them unsuitable for the purpose. They will be used as expedient until more satisfactory arrangements are made. The existence of a special transmitter in Anchorage will also obviate the inconvenience experienced from the restricted broadcasting hours of the television station. Two frequency allocations in the range just above 200 mc have been obtained.

In order to investigate the diffraction pattern of the mountains more fully, it is planned to make tests with airborne equipment before September 1955. A light airplane (Cessna 140) is being equipped with a vertically polarized, ground-plane antenna and a lightweight receiver for preliminary flights. In addition, a similar antenna is being fabricated for a C-47 airplane to be furnished by Ladd Air Force Base for one day's flying at altitudes up to 20,000 feet. It is anticipated that these flights will either confirm or disprove the focusing effects observed previously behind the two principal mountains, McKinley and Foraker.

C. Scatter of V.H.F. Radio Waves by Mountains

Evidence of strong, scattered signals from mountains of the Alaska Range has been obtained from the observations at Minchumina. During the spring of 1954-55 two television stations were established in Fairbanks on the same channels (2 and 11) as those in Anchorage. From this time, it became difficult to distinguish between the two channel 11 stations; in fact, the television receiver at Minchumina usually presents the video from Anchorage and the audio from Fairbanks. The bearing from Minchumina to Anchorage is 156.5° true, no signal being detected from the azimuth of Fairbanks. It appears, therefore, that the Fairbanks signal is being propagated to Lake Minchumina via mountain scatter from the mountains to the east of Mt. McKinley. The total path length involved in this case is approximately 220 miles as compared with the direct path of approximately 150 miles. It is reported that the Fairbanks audio signal is of good quality, but the video signal is useless. It is believed that this is due to the multiplicity of scatter paths involved, which tend to blur out the synchronizing pulses required for a stable picture. Calculations based on the strength of the echo received from Mt. McKinley using the 106 mc equipment, suggest that this mountain scatter explanation is a plausible one. It is planned to continue this investigation of mountain scatter, using the 106 mc radar at College.

D. <u>Ionospheric Absorption</u>

In February 1955 communications personnel of the 58th Weather Reconnaissance Squadron of the Eielson Air Force Base visited the Geophysical Institute in connection with some of their communications problems. As a result, it was agreed that a special series of weekly ionospheric absorption reports be prepared by the Institute, to enable the squadron to identify which of their communication failures could be attributed to ionospheric absorption. These reports were based on continuous observations of zenithal absorption of 30 mc extra-terrestrial radio waves, of the type described by Little[23].

These reports, though limited to the zenith at College, nevertheless proved of considerable value in identifying the source of communication failure. In general, it was found that almost all communication failures could be immediately attributed to absorption, thereby eliminating doubts concerning the use of an appropriate frequency (i.e. below the M.U.F.) and also any doubts concerning equipment or personnel failures.

On many occasions, some zenithal ionospheric absorption was reported at College at times when H.F. communications to distant aircraft were satisfactory. This is probably due to a combination of two factors:

1. The sensitivity of the absorption measurements is such that absorption can be detected before it is sufficiently intense to prevent H.F. communication, and

2. the possibility that the absorption may be localized at approximately the latitude of the auroral zone.

As a result of this work, the recommendation has been made to the Squadron that, where possible, flights during equinoctial months be made at night-time. This recommendation is based on our observations that arctic ionospheric absorption is predominately a day-time phenomenon, and is most likely to be severe during equinoctial months. It is expected that in this way the number of flights which have to be aborted due to failure of communciations will be considerably reduced.

SECTION V

FUTURE PLANS

The future plans for the research on this contract are briefly:

Task 1 The work on this task will be held in abeyance until equipment is supplied. It is hoped that a C-4 ionospheric sounder will be available within the next twelve months.

Task 2 Observations of aurora with the SCR-270 radar operating at 106 mc will continue as required in special studies. A radar operating at 200 mc is on order, and it is hoped that delivery and installation of the equipment will be in time to take full advantage of the coming auroral season. Although the radar "sees" auroras regardless of cloud or daylight, the preliminary studies require visual or photographic observations for comparisons.

Task 3 The work on this task is being discontinued.

Task 4 It is planned to use two or three all-sky cameras to study the growth of an auroral display over Alaska and vicinity, and also to study the detailed development during a display in conjunction with the appearance and the amount of absorption of extra-terrestrial radio waves, as well as with other terrestrial phenomena. Studies using the observations with the photoelectric photometer as an index of auroral activity will be continued.

Task 5 Observations of "whistlers" will be continued, at least at intervals, during the coming year in order to establish any seasonal variations. Also, observations of whistlers and other low frequency radio noise will be made during intense auroral displays.

Task 6 The diffraction of radio waves over mountains is continuing. Excellent cooperation and interest by the Air Force personnel assigned in Alaska and by the personnel of the television stations at Anchorage and Fairbanks is greatly assisting this task. Observations using low-powered equipment and an isolated mountain is planned for the near future.

The scattering of radio waves, particularly using the SCR-270 radar operating at 106 mc, will be continued as time permits.

The measurement of absorption using extra-terrestrial radio waves will be considerably expanded during the coming year, primarily on other contracts, in order to give an idea of the distribution of absorption across the auroral zone. These data will be used in conjunction with propagation of radio waves in the arctic as well as with auroral and ionospheric disturbances.

SECTION VI

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SECTION VII

LIST OF FIGURES

SECTION IV

PERSONNEL

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C. G. Little	Project Supervisor
K. L. Bowles	Research Assistant
R. B. Dyce	Research Assistant
R. B. Roof	Research Assistant
G. W. Swenson, Jr.	Research Assistant
H. F. Bates	Researcher
R. S. Leonard	Researcher
J. H. Pope	Researcher
W. B. Murcray	Researcher
E. Stiltner	Researcher
Soren Andersen	Electrical Engineer
R. N. Shoup	Electronic Technician
R. A. Stark	Electronic Technician
M. J. Young	Electronic Technician
T. N. Davis	Senior Technician
V. C. Fetzer	Technician
J. W. Garrison	Technician
J. E. Kahle	Technician
L. T. Kegler	Technician
Gail Luck	Technician
C. J. Smith	Technician